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BASIC RESEARCH PLAN

DEPARTMENT OF DEFENSE
DEPUTY UNDER SECRETARY OF DEFENSE
(SCIENCE AND TECHNOLOGY)

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The *Basic Research Plan* is a dynamic document that is updated every two years. It describes ongoing work as well as planning activities and accomplishments that can be traced to earlier basic research. It serves to inform both performers and managers of the research as well as to provide military planners with an overview of the entire program. The plan's ultimate purpose is to provide the warfighter with superior and affordable technology, with a particular focus on revolutionary capabilities.

This fourth edition of the *Basic Research Plan* is an updated and amplified version of the February 1999 plan. The plan serves to focus, integrate, and describe the Department of Defense investment in a world-class research program. Linking basic research to broad, revolutionary, 21st century military capabilities requires planning. In the case of a long-range strategic program like basic research, planning involves not so much solving individual problems, but rather exploring whole strategic technology areas that address envisioned future military capabilities. Historically, basic research has initiated scientific and engineering breakthroughs that started technological revolutions. Our challenge is to find and open new doors to technology.

A new emphasis in this fourth edition is placed on speeding the transfer of rapidly advancing basic research into technology areas with the potential for achieving high military payoff. Accomplishing this objective requires earlier and more informed planning based on broad strategic Defense requirements. Suitable ongoing research efforts are therefore directed, but without interfering with the basic research process itself, toward a common strategic goal that has the potential of attaining radically new military capabilities. This is the purpose of the *Strategic Research Areas*, which are described in detail. This year's plan is again a joint product of the Office of Basic Research working with the research Offices of the Military Departments and Defense Agencies.

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Deputy Under Secretary of Defense
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EXECUTIVE SUMMARY

One legacy of World War II was the excellent cooperation between the military and academia that has lasted for more than half a century. The first federal research agency, the Office of Naval Research (ONR), was established by Act of Congress in 1947. It was soon followed by the Army Research Office (ARO) and the Air Force Office of Scientific Research (AFOSR). The Defense Advanced Research Projects Agency (DARPA) was established in 1958, largely as a response to an emerging threat signaled by the Soviet Sputnik. Funding for basic research in the Department of Defense (DoD) has slipped appreciably for several years in comparison with that in other federal agencies. Defense basic research needs to be sustained strongly if future technological surprises are to be avoided.

This year's *Basic Research Plan* (BRP) presents a fairly comprehensive overview of the program. Ten tri-service Scientific Planning Groups (SPGs) are responsible for coordinating 12 disciplinary areas. Two pairs of related technologies, four in all, come under two SPGs. Each disciplinary area is described in some detail. Multidisciplinary programs are also described, including the Multidisciplinary University Research Initiative grants (MURIs) and the Strategic Research Areas (SRAs).

World-class research requires world-class researchers. The program helps educate and train thousands of technical students at numerous universities, and contributes to the infrastructure through the Defense University Research Instrumentation Program (DURIP). Defense basic research grants and contracts are unclassified, and results may be published without restriction. This policy benefits not only the performers (most of them at universities) but also DoD in that it provides DoD a “window on the world” of science and engineering.

Defense basic research has played the midwife at the birth of technologies—such as microelectronics, the Internet, the Global Positioning System, and satellites—which have benefited not only DoD but also society at large, and created the high-technology world of today. We cannot afford to overlook any promising technology area and must maintain a balanced basic research portfolio. DoD obtains further leverage by coordinating with other research agencies—for example, taking the lead jointly with the National Science Foundation (NSF) in kicking off the National Nanotechnology Initiative (NNI), a likely candidate for another technology revolution.

CHAPTER I
INTRODUCTION

A. VISION

The vision of the Basic Research Program of the Department of Defense (DoD) is to invest in world-class basic research programs that will:

- Provide the scientific and engineering basis for new technologies that will ensure the technological superiority of U.S. forces in future engagements anywhere in the world, whether waging war or enforcing the peace.
- Investigate a broad set of technology options to exploit breakthroughs as well as to make steady advances aimed at maintaining U.S. technological superiority.
- Keep U.S. scientists and engineers well informed on technology developments anywhere in the world to anticipate and meet new threats that may arise to national security.

B. MISSION

The mission of the DoD Basic Research Program is to continue to conduct comprehensive basic research that will:

- Provide a strong foundation for new and future technologies required to support DoD's mission by ensuring availability of trained scientific manpower in technologies critical for defense, and the necessary facilities in academia, industrial laboratories, and DoD establishments to perform advanced research.
- Assist in the development of revolutionary military capabilities and systems so that the U.S. military continues to be the best in the world, by providing a stream of basic research results transitioning into applied research and advanced development to ensure that the best available technology reaches the warfighter in the shortest possible time.
- Keep DoD informed of worldwide technological developments and opportunities that might affect U.S. defense—for better or for worse—by focusing on technologies of critical importance to national defense, while maintaining a balanced research program ready to exploit unexpected opportunities or counter unforeseen technological threats.

C. FOCUS ON WARFIGHTER NEEDS

The DoD *Defense Science and Technology Strategy* (Ref. 1), authored by the Office of the Deputy Under Secretary of Defense for Science and Technology (ODUSD(S&T)), states in part: "The mission of the Defense Science and Technology (S&T) Program is to ensure that the warfighters of today and tomorrow have superior and affordable technology to support their missions and provide revolutionary war-winning capabilities. To do this, we must understand the warfighters' needs."

In today's global environment, the U.S. military must be able to dominate the full range of military operations from humanitarian assistance to major theater warfare. The key to achieving this full-spectrum dominance will be the ability to acquire information superiority and the technologies that enable it. In addition, technologies that make our forces lighter, more mobile, and more lethal are also keys to warfighter success. Technological superiority is a principal characteristic of our military advantage.

The Defense S&T Program will address the Joint Warfighting Capability Objectives (JWCOs), articulated in the *Joint Warfighting Science and Technology Plan* (JWSTP) (Ref. 2), which cover a broad range of future warfighting capabilities. The Defense S&T Program, of which basic research is a part, addresses the JWCOs by focusing a significant portion of the S&T investment in five areas: information assurance, battlespace awareness, force protection, reduced cost of ownership, and maintaining a balanced basic research program.

1. Information Assurance

Information assurance remains a core research area for DoD. Research activities related to cyberterrorism and better protection of our own critical information systems, both on the battlefield and throughout the country, must be a priority.

2. Battlespace Awareness

Battlespace awareness (situational awareness and understanding coupled with information assurance) is needed to provide real-time knowledge from "sensor-to-shooter." In principle, smart sensor webs integrating networks of sensors with cognitive readiness systems will enable U.S. warfighters to exploit battlespace awareness. Basic research is needed to develop real-time imagery with automatic target recognition capability. New physical models employing dynamic, intelligent databases are needed to enable real-time intelligence for the warfighter. The extremely large amount of information will require technical tools to help sort, mine, understand, and act in real time.

3. Force Protection

The 21st century warfighter must have capabilities to survive, fight, and win in a contaminated environment. Investments are needed to support research and technology development to provide improved capabilities against chemical and biological threats while minimizing adverse impacts on our warfighting capability.

4. Reduced Cost of Ownership

An increased emphasis is being placed on affordability as a leading investment factor governing the S&T program. Research must be conducted to reduce the cost of operating and maintaining force readiness. One example is the research on improving combustion efficiency of mechanical energy generators and thereby reducing the operating transportation systems and associated logistics costs.

5. Maintaining a Balanced Basic Research Portfolio

New military capabilities and operational concepts emerge from basic research. Basic research is a long-term investment with emphasis on opportunities for military application far in the future. Furthermore, it contributes to our national academic and scientific knowledge base by providing substantial support for all engineering. Basic research investments over a long period of time have contributed significantly to new warfighter capabilities (e.g., stealth, lasers, infrared night vision, and microelectronics for precision strike). Many of these major advances were unpredictable. No promising avenue of research should be neglected. Areas of emphasis may change, but it is important to maintain a balanced portfolio so as to be prepared to deal with any unforeseen developments wherever in the world they may occur.

Since most applications of research require progress across several disciplines, an increased emphasis has been placed in recent years on multidisciplinary research activities, of which the Multidisciplinary University Research Initiative (MURI) program is a prime example (see Chapter V). In another example, the Strategic Research Areas (Chapter VI) build on ongoing research in single disciplinary areas by coordinating them into multidisciplinary efforts to foster earlier applications than might otherwise have been possible.

D. THE PAYOFF

It is hard to predict the breakthroughs and revolutionary military capabilities to be gained from investing in basic research; however, we know that many of our current military capabilities and systems can be traced back to earlier basic research programs. Many payoffs to the nation have occurred from timely DoD investments in basic research. Typical of the successes of research transitioned to actual systems in the field are:

- Global Positioning System (GPS)
- Night vision technology
- Airborne Laser (ABL)
- Internet and World Wide Web
- Satellite technology.

1. Global Positioning System

Navies have always been concerned with precision navigation on a featureless ocean. Almost 300 years ago, in 1714, the British Navy offered an award of 20,000 pounds, a huge sum, for a timekeeper that would maintain an accuracy of about 20 miles after a journey from the British Isles to the West Indies. The horologist (watchmaker) John Harrison spent the next 45 years developing such a timepiece. It was tested successfully at sea in 1762 and had an accuracy of about 1 mile. The British Navy paid Harrison in full in 1773, nearly 60 years after the award was first offered. The U.S. Navy, working through the Office of Naval Research (ONR) some 200 years later, was more efficient when it started basic research that led to an atomic clock (a hydrogen maser) in about half the time, and with an accuracy corresponding eventually to a few feet in all three dimensions anywhere on earth.

The technology underlying the hydrogen maser clock relied on research from atomic spectroscopy studies by Professor Isidor Rabi at Columbia University supported by ONR. Later, advances in satellite technology, coupled with such ultraprecise atomic clocks, provided precision location and navigation. The ONR-funded research, coupled with Air Force-supported research into coded transmission techniques, provided precise ranging and timing data anywhere on earth from a constellation of GPS satellites. These satellites provided support for precision weapon delivery systems that could operate in all weather conditions and engage targets with an accuracy of the order of 1 meter. Steady investments in basic research over many years were amply repaid by the superiority of our precision weapon systems. The GPS was a tremendous asset during both the Desert Storm and Kosovo engagements. The civilian spinoff of GPS is well known.

2. Night Vision Technology

The development of thermal imaging devices, based on long-term basic research in microelectronics, signal processing and especially advanced materials, has permitted the U.S. Army to "own the night." The original theoretical techniques were proposed in the 1950s. Basic research over a 30-year period into the science of semiconductor materials, metal-semiconductor interfaces and photoemission phenomena, and masers and lasers, led to significant military capabilities to image targets at night. The successful use of thermal imaging systems in Desert Storm vividly demonstrated the benefit of these systems, giving the U.S. forces a decided military advantage. This successful application was ample justification for basic research investments made by the Army Research Office (ARO) to advance technology over a period of 35 years; moreover, it has now resulted in commercial and medical applications as well.

3. Airborne Laser

The current ABL program was enabled by basic research—supported by the Air Force Office of Scientific Research (AFOSR)—into laser beam generation techniques and propagation through the atmosphere. Successes in solving the atmospheric turbulence problem have revolutionized the ability to transmit laser beams through the atmosphere and have dramatically improved the ability of ground-based telescopes to obtain images of astronomical objects that rival those taken from space by the Hubble Space Telescope. Much of this work was started before definitive military requirements were established.

4. Internet and World Wide Web

Another significant breakthrough was the initial development of the Internet by the Defense Advanced Research Projects Agency (DARPA). Many of the investments in basic computer science and technology led to the ARPANet, which eventually evolved into the World Wide Web—impacting every aspect of civilian and military life. This modest DoD research investment has spawned an entire multi-billion-dollar information technology industry, which, in turn, has fueled the nation's economy.

5. Satellite Technology

DoD's early research into satellite technology and space systems has led to today's use of satellites for communications, navigation, and surveillance (including weather observations), thus making the United States more secure through rapid worldwide communications, precision weapons, and valuable intelligence. Without the DoD investment, the space communications industry would have been slower to develop.

CHAPTER II
DEFENSE BASIC RESEARCH PROGRAM OVERVIEW

A. PURPOSE

Basic research is concerned mostly with the development of fundamental knowledge and understanding, generally without regard to a specific application. Specific applications are generally addressed by applied research, although to state hard and fast rules is impossible. Rather, basic research should enable many potential applications and uses.

Likewise, *defense* basic research is concerned with the development of fundamental knowledge and understanding, focusing on future technology applications benefiting national defense. Although end uses may differ, the character of defense basic research is mostly indistinguishable from any other research into a similar scientific or engineering area. Where it *is* distinguishable is more by the researcher and his or her motivation than by the research as such. That is, the performer should always be aware of opportunities to benefit defense even when his or her research blends into similar research activities, supported, say, by the National Science Foundation. Such blending is in fact highly desirable, as it increases the influx of fresh ideas for defense applications.

B. MANAGEMENT

Defense research is managed mainly by or through the three service research offices (the Army Research Office (ARO), the Office of Naval Research (ONR), and the Air Force Office of Scientific Research (AFOSR)) as well as the Defense Advanced Research Projects Agency (DARPA). Oversight of the entire basic research program is the responsibility of the Director for Basic Research in the Office of the Deputy Under Secretary of Defense for Science and Technology (DUSD(S&T)), located in the Office of the Secretary of Defense (OSD). The Multidisciplinary University Research Initiative (MURI) program cuts across disciplines and services and is directed (not just overseen) out of the Basic Research Office, while being managed by the "OXRs" (collectively the ARO, ONR, and AFOSR) as well as DARPA, for closer interaction with their single-discipline researches.

C. OBJECTIVES AND CONTENTS

Defense basic research is focused in those fields of the physical, environmental, and life sciences and engineering appropriate to meeting long-term national security needs. The research is often farsighted and risky, but with projected high payoffs in terms of future military systems. Defense basic research aims to give a jump-start to critical technologies that provide the basis for technological progress. As the results of defense basic research are transitioned, they support key military visions and concepts that provide new and improved military functions and capabilities.

Achieving these objectives in the coming decades requires the DoD's S&T programs to:

- Maintain technological superiority in warfighting equipment
- Provide knowledge basis for technical solutions for achieving the future joint warfighting capabilities

- Balance basic and applied research in pursuing technological advances
- Incorporate affordability as a design parameter.

Joint Vision 2020 (Ref. 3) defines the key military operational concepts for the 21st century as:

- Dominant maneuver
- Precision engagement
- Focused logistics
- Full-dimensional protection.

Each of these concepts is explicitly based on continued technological innovation and on the ability to achieve information superiority.

The services' visions have been built from these bases: for the Army, *Army Vision 2020* (Ref. 4); for the Air Force, *Global Engagement: A Vision for the 21st Century Air Force* (Ref. 5); for the Navy, *Forward…From the Sea—The Navy Operational Concept* (Ref. 6) and the *Naval Long Range Planning Objectives* (Ref. 7); and for the Marine Corps, *Operational Maneuver From the Sea* (Ref. 8). Together these documents describe the concepts of operations and define the capabilities needed to meet the challenges of the 21st century. They set the goals for DoD and the services in looking to the future and in defining their investment in science and technology. Basic research is a vital part of the S&T program, providing technological opportunities and fundamental understanding of processes and materials on which to base future military technologies.

The core research disciplines are described in Chapter IV. The disciplines are coordinated by tri-service committees and by the Scientific Planning Groups (Appendix A) with DARPA participation where appropriate, as described in Chapter IV.

D. COMPOSITION OF PROGRAM

The Basic Research Program supports a broad range of activities spanning many scientific and engineering disciplines to provide a strong technical foundation to meet the diversified needs of the DoD services, agencies, and organizations. Since most of the research areas of interest to the DoD cut across scientific disciplines, the Basic Research Program also supports research that involves multiple fields and disciplines and multiple university teams.

In addition to the core research programs, strong interdisciplinary/multidisciplinary programs exist involving the following components:

1. Multidisciplinary University Research Initiative

The Multidisciplinary University Research Initiative (MURI) is carried out by multidisciplinary academic teams, often involving more than one university, working on research projects of strategic interest to the DoD; MURI research projects are part of the University Research Initiative (URI) program, which is a multifaceted program described in Chapter V.

2. Strategic Research Areas

Strategic Research Areas (SRAs) combine projects from different disciplines and involve multidisciplinary teams to advance progress in specific strategic areas of interest to DoD. SRA research efforts are not projects in themselves; rather, they take advantage of ongoing basic research projects that might be coming close to application if combined with other research projects. This combination is accomplished by providing common objectives that these research projects could share, so as to increase the opportunities for earlier transitions. SRAs are described in more detail in Chapter VI.

3. Government–Industry Cooperative University Research Program

The Government–Industry Cooperative University Research (GICUR) Program combines industry know-how and funding with DoD interests and funding to support university research projects of mutual interest to industry and government.

E. SCIENCE EDUCATION AND INFRASTRUCTURE SUPPORT

The DoD Basic Research Program also provides education and infrastructure support for the education and training of future talented scientists and engineers and for the improvement of research equipment and instrumentation. Students and modern equipment and facilities are essential ingredients for scientific research.

The Basic Research Program provides for the education and involvement of graduate and post-doctoral students and young investigators through a variety of policies and programs designed to create a new generation of scientists and engineers who will perform research of importance to DoD and the country in the future. Many individual research grants to universities, as well as multidisciplinary university research grants (such as the MURIs), often include financial support for graduate students and post-doctorates in addition to research support for university faculty. Education and training fellowships are provided to outstanding individual scientists and engineering graduate students as part of the MURI program element.

DoD also sponsors the National Defense Science and Engineering Graduate Fellowship Program to provide fellowships to substantial numbers of graduate students majoring in science and engineering areas of interest to DoD. DoD is committed to supporting students in scientific and engineering areas vital to national security and to ensuring that the need for scientists and engineers will be met in the future.

Research instrumentation is an essential part of the research infrastructure that enhances scientific progress and productivity. Special equipment programs link the purchase of modern research equipment to the support of DoD relevant research. The Defense University Research Instrumentation Program (DURIP) is focused on improving critical research infrastructure for purchasing modern research instrumentation to support research in areas of interest to DoD.

F. TRANSITIONS FROM BASIC RESEARCH TO APPLICATIONS

In order to be successful, DoD basic research results must eventually lead to providing technologically superior weapon systems and products at a more affordable cost. Basic research must transition to enable development and engineering programs that results in a rational, beneficial, cost-effective, and timely manner.

As outlined in Section I.D, the ultimate payoff of basic research is in moving leading-edge technologies into the field. DoD has an excellent record of transitioning technology; however, increased emphasis should be placed on shortening the time for insertion into fielded systems. Insertion will require planning for earlier transitioning of mature research projects.

Planning for earlier transitioning is one of the principal objectives of the MURI research grants to universities, the SRA teaming of OXR managers in selected strategic research areas, and the GICUR research requiring university–industry connections.

CHAPTER III
PLANNING PROCESS

The DoD basic research planning process is an integral part of the DoD science and technology (S&T) planning process. The DoD Basic Research Plan supports the vision and goals of the *National Security Science and Technology Strategy* (Ref. 9), *Joint Vision 2020* (Ref. 3), and *Defense Science and Technology Strategy* (Ref. 1). Taken together, the *Joint Warfighting Science and Technology Plan* (JWSTP) (Ref. 2), the *Defense Technology Area Plan* (DTAP) (Ref. 10), and this *Basic Research Plan* describe DoD's overall S&T program. The Office of Basic Research in OSD and the service research offices jointly develop the Basic Research Plan.

The biennial basic research cycle begins with project-level reviews at the individual research agencies (AFOSR, ARO, ONR, DARPA, and the Ballistic Missile Defense Organization (BMDO). These sessions are followed by a program-level review, called the Technology Area Review and Assessment (TARA) by a panel of non-DoD experts. One such TARA panel reviews the DoD Basic Research Program. Budget projections for the next year are prepared and submitted as part of this process. The Basic Research Plan (BRP) is based in part on the results of the TARA review.

A. ROLE OF SERVICES AND AGENCIES IN BRP DEVELOPMENT

The DoD services and agencies develop their own specific plans and goals. As many of their technology goals overlap, plans for basic research are coordinated through the Basic Research Office as part of the Defense S&T Reliance Process. The majority of the scientific work constituting the DoD Basic Research Program involves the 12 technical disciplines that are coordinated by Scientific Planning Groups (SPGs) consisting of disciplinary program managers from each of the services. The SPGs and the Strategic Research Area (SRA) coordinating committees provide coordinated tri-service oversight for research in their respective areas. The SPGs concentrate on their specific disciplinary areas, whereas the SRA coordinating committees concentrate on interdisciplinary approaches in their focus areas.

Each service and agency is responsible for developing, reviewing, and assessing its individual research plans, which are coordinated by the SPGs. As part of the TARA process, the Office of Basic Research reviews and assesses the quality, technical content, and focus of the overall service and DoD-wide programs.

B. BASIC RESEARCH AND THE RELIANCE PROCESS

The DoD Basic Research Program is executed within the framework of the DoD S&T Reliance process, and overseen by the Office of Basic Research. The biennial TARA process is used to monitor the quality, coordination, DoD relevance, and realistic funding of the research projects. The Director of Basic Research chairs the TARA meetings. The TARA review teams consist of technical experts from academia, industry, and not-for-profit research organizations.

1. Defense Committee on Research

The Defense Committee on Research (DCoR) is chaired by the Director of the Office of Basic Research, and the Directors of the Army, Navy, and Air Force basic research organizations and basic research representatives from DARPA and BMDO. The DCoR meets on a regular basis to share information and coordinate among the participants.

2. Defense Science and Technology Advisory Group

The results of the TARA reviews are then presented to the Defense Science and Technology Advisory Group (DSTAG). The DSTAG is chaired by the Deputy Under Secretary of Defense for Science and Technology (DUSD(S&T) and is composed of key individuals in leadership roles for S&T in OSD, the services, and defense agencies. The DSTAG provides feedback to the Office of Basic Research and the services and agency basic research offices. The DSTAG completes the TARA process by providing guidance for program objective memorandum (POM) submission, which affects the budget submissions for the program elements. The latest BRP becomes a source document for the TARA process (as does the DTAP for technologies beyond basic research), and the TARA process in turn affects the program described in the BRP that follows the latest TARA. BRP publication and TARA reviews occur in alternate years, making up a 2-year cycle.

The role of these and other groups in evaluating the Basic Research Program as a whole is discussed in Section D.

C. A FLEXIBLE AND BALANCED INVESTMENT PORTFOLIO

The DoD services and agencies coordinate their individual research investment plans through the Defense S&T Reliance process as described in the previous section. The Defense S&T Reliance process establishes and implements joint planning, joint research partnerships, or lead-service assignments among the military services for the technical disciplines of the BRP. Each research area is examined closely by its participants to establish areas of common interest and to provide opportunities for cooperative leverage. Such joint planning and coordination of programs provides a broader research effort and more efficient support of a more balanced investment portfolio than could be provided by a single service effort. For example, the Army emphasizes information technologies (mathematics, computer sciences, electronics) for digitizing the battlefield, materials science for armor and soldier protection, optical sciences for target recognition, chemistry and biological sciences for chemical and biological agent defense, and geo-sciences for terrain-related knowledge relevant to battlefield mobility prediction. The Navy has a full-spectrum program that places special emphasis on a wide range of ocean science activities, including predicting weather and currents, mapping the ocean floor, using acoustics to detect objects in the ocean, and conducting biotechnological research such as understanding and mimicking communications between mammals. Air Force expertise is concentrated in the aerospace sciences, materials, physics, electronics, chemistry, life sciences, and mathematics for application to air vehicles, space systems, and communications, command, control, computers and intelligence (C^4I).

Besides directly supporting their military departments, DoD laboratories serve as agents for DARPA, BMDO, and other defense agencies in providing research activities and functions. These programs interact and are coordinated by the SPGs, discipline by discipline, and through the OSD-sponsored multidisciplinary programs. The OSD Basic Research Office working with the DCoR exercises oversight over the research program as a whole.

Even though DoD provides only about 6 percent of all federal basic research funding (Chapter VII, Figure VII–1), DoD is a significant source of federal funding of university research in several disciplines. DoD is a major funding source in electrical and mechanical engineering (providing 71 percent and 63 percent, respectively, of the R&D support in this area), computer sciences (42 percent), and mathematics (22 percent) (more details in Chapter VII, Table VII–1). DoD is a major source of funding in materials, optics, and oceanography. In some specific areas, DoD is the only source of basic research funding (e.g., in the support of vacuum electronics needed for radiation-hardened electronics used in radar and space systems).

D. QUALITY AND RELEVANCE OF BASIC RESEARCH

This section summarizes how DoD ensures the quality and relevance of its Basic Research Program.

1. Scientific Planning Groups

The primary responsibility rests with the SPGs. A list of the current SPGs and their members is provided in Appendix A. The SPGs meet regularly to coordinate related activities in their disciplinary areas. The coordination of the DoD Basic Research Program is successful because of the quality of the SPG leadership.

2. Defense Committee on Research

The DCoR coordinates at the next higher level among the service and DARPA basic research offices. The DCoR serves as the primary organization to establish a coordinated research program that supports the DoD mission. The committee also assists in the clarification of issues and policy. The DCoR supports the overall preparation of the BRP submitted to DUSD(S&T).

3. TARA Review Panels

TARA Review Panels, consisting of technical experts from academia, industry, and not-for-profit organizations, evaluate the DoD Basic Research Program for vision, technical content, depth, and quality. The results of the TARA reviews are provided to the DSTAG.

4. Defense Science and Technology Advisory Group

The DSTAG provides advice to DUSD(S&T) on the quality and content of the overall DoD science and technology program, including the Basic Research Program. The DSTAG provides feedback to the Office of Basic Research and the defense services and agencies regarding program content and quality. The DSTAG guides preparation of the POMs issued by the services and defense agencies and assists in the development of priorities for the major program elements.

5. Deputy Under Secretary of Defense for Science and Technology

DUSD(S&T) uses the TARA process to ensure the quality of the research conducted by the DoD components, and to keep the focus on the DoD mission. The Director for Basic Research exercises oversight over the entire defense basic research program and reports to DUSD(S&T), who provides feedback and guidance to the Director for Basic Research in the context of the larger S&T program and other DoD strategic interests.

CHAPTER IV
BASIC RESEARCH AREAS

The great majority of the scientific research work constituting the DoD Basic Research Program involves 12 technical disciplines:

- Physics
- Chemistry
- Mathematics
- Computer Sciences
- Electronics
- Materials Science
- Mechanics
- Terrestrial Sciences
- Ocean Sciences
- Atmospheric and Space Sciences
- Biological Sciences
- Cognitive and Neural Science.

As mentioned in Chapter III, each discipline is coordinated by a Scientific Planning Group (SPG), except for two pairs of closely connected disciplines: (1) Mathematics and Computer Sciences and (2) Ocean and Terrestrial Sciences. Because of their close connection, each pair of disciplines is handled by one SPG, making 10 SPGs for 12 disciplines.

In this chapter there is a brief description of each discipline along with a table showing specific service interests and areas of commonalities. The distribution of funding among the disciplines is summarized in Section K at the end of the chapter.

A. PHYSICS

Physics is the scientific discipline devoted to discovering and employing the fundamental principles which underlie the laws of nature. Physics research investigates novel phenomena, formulates and tests new concepts and theories, develops new experimental tools and techniques, performs new measurements, develops new computational techniques, and applies all of the above to developing useful devices and novel or improved materials. DoD Physics research has the goal of transitioning scientific progress and breakthroughs into enhanced DoD capabilities. These materials and devices have the potential to extend and enhance the operational capabilities of many different types of military equipment and systems in the areas of weapons, weapons platforms, sensors, communications, navigation, surveillance, countermeasures, and information processing. As such, the Physics SPG crosses all four elements of the *Joint Warfighting Science and Technology Plan* (Reference 2) by supporting S&T contributions to military needs: ground, sea, air, and space sensor research; quantum information science research for greatly enhanced computational capabilities and ultrasecure communications and sensor improvement research; guidance and control; lethality technologies; high-power microwaves that can be used to neutralize, disable, disorient, or confuse without lasting effects; atomic clock improvements, which in turn affect GPS performance improvements; deployable unattended sensors; and techniques for detecting and evaluating the existence of manufacturing capabilities for weapons of mass destruction.

The definition of service specific research in Physics clearly follows lines of respective mission applications. The Army focuses on soldier and land platforms with a strong emphasis on smaller, lighter, more lethal, and more survivable platforms; the Navy on surface ships, including carriers and their aircraft, and submarines; and the Air force on atmospheric and space flight applications. The need for lightweight, small devices for airborne platforms by the Air Force has resulted in a program to develop visible laser technology for possible use in optical countermeasures. The Army has an active program in compact displays and detectors to support the combat soldier, in addition to programs for sensor protection from laser radiation for all sensors including soldiers. The Army also has a program to significantly improve target detection and identification capabilities, especially under highly cluttered or obscured conditions, by developing ultra-sensitive atom optics based detectors, and by advancing unconventional optics techniques such as integrated computational imaging. The Navy pursues research to develop blue-green lasers for underwater communications and mine detection. Naval research in acoustics is focused on physical acoustics and underwater acoustics involving propagation and transducers. Application of nonlinear dynamics to signal detection and classification is of high naval interest. The Air Force has an active program in optical compensation for the imaging of space objects through the atmosphere.

DoD Physics research falls into four general subareas: radiation, matter and materials, energetic processes, and target acquisition.

1. Radiation

Research in radiation runs the gamut from the x-ray to the microwave regime. Advanced radiation sources are needed to satisfy DoD requirements, including for C^3I, radar, sensors, electronic warfare, and directed-energy weapons. The Air Force also has the tri-service lead in directed energy under reliance, and funds research in this area that benefits the three services. In addition to radiation sources, this area involves the propagation of radiation and detection of objects using radiation in different military environments. Research thrusts include high-power fiber lasers, ultraviolet and blue-green lasers, high-power microwaves, photonic band engineering, nonlinear optics, and optical compensation.

2. Matter and Materials

Matter and materials research ranges from nanoscale (atom sized) systems to macroscale (e.g., high T_c superconductors) systems that impact many DoD systems, such as the Global Positioning System performance improvements (using atom traps and their impact on atomic clocks), liquid crystal and adaptive gating based optical limiters for sensor protection, and low observables for stealth. Atom optics and quantum effects are being used to develop ultra-sensitive detectors, and unprecedented computational and communication capabilities. In addition, nanoscience research is being pursued to develop ultra-small sensors and materials with unique properties for signature control, electronics, and armor.

3. Energetic Processes

Many DoD systems are impacted by research in energetic processes because they have critical power-generation and high-voltage requirements. This area involves elements in high voltage, plasma, power generation, and energy storage. Representative research thrusts include mobile power sources, thermo-photovoltaics, compact accelerators, pulsed power, ultra-high-field physics, and plasmas (neutral, non-neutral, collisionless, and collisional). Neutral plasma effects can provide stealthy conditions for DoD aircraft and satellites.

4. Target Acquisition

The survivability of friendly and unfriendly platforms (ships, tanks, aircraft, spacecraft) and systems (e.g. communications, command, control, and intelligence (C^3I), radar) depends on advances in the area of target acquisition. The area involves an element within the oceanographic and atmospheric arena. Research thrusts are focused on detection and displays, and the scientific underpinning of automatic target recognition. The Army needs to see through the dust of battle, calling for advances in detectors, optics, and imaging science. The Air Force must accurately locate and image space objects through atmospheric distortions. Naval research on acoustic and nonacoustic underwater detection and classification of submarines and mines has employed nonlinear dynamics signal processing methods and nonlinear stochastic resonance detectors.

Table IV–1 breaks down the Physics discipline into areas of specific research and areas of commonality.

Table IV–1. Service-Specific Interests and Commonality in Physics

Subarea	Army (A)	Navy (N)	Air Force (AF)
Radiation Sources Detection Propagation	Photonic band engineering Sub-millimeter wave (MMW) research Tunable IR (infrared) lasers	X-ray sources Blue-green lasers Quantum noise	Optical compensation Microwave sources
	Areas of Common Interest: optical image processing (A, AF); ultra-fast electro-optics (EO) (A, N, AF); novel lasers (A, N, AF); nonlinear optics (A, N, AF); optical diagnostics and testing (A, N, AF); coherent free-electron radiation sources (A, N, AF)		
Matter and Materials Optical Atomic Molecular Plasma	Quantum information science Low observables Soldier displays Sensor protection	Physical acoustics Energetic and nonlinear IR materials	Visible lasers Semiconductor lasers
	Areas of Common Interest: ferroelectrics (A, N); nanostructures (A, N, AF); surfaces and interfaces (A, AF); atom optics (A, N, AF); high-T_c superconductors (N, AF); atom traps (A, N, AF); computational physics (A, N, AF); nonlinear control (A, N, AF)		
Energetic Processes High voltage Plasmas Power generation	Mobile power sources	Compact accelerators Pulsed power Ultra-high fields Beam plasma dynamics	Non-neutral plasma effects
	Areas of Common Interest: non-neutral plasmas (N, AF); collective phenomena (N, AF)		
Target Acquisition Oceanographic Atmospheric	Integrated sensory science Imaging science Unconventional optics Solitonic computing	Nonlinear acoustics Sound/fluid/structure interactions Active and passive sonar Stochastic resonance detectors	Atmospheric discharges Atmospheric neutral density impacting spacecraft Space environmental forecasts
	Areas of Common Interest: ionospheric modification and propagation (N, AF); nonlinear dynamics/chaos (A, N, AF)		

B. CHEMISTRY

Chemistry research directly affects a wide range of critical DoD systems and missions. Such research is central to developing advanced materials for specific DoD applications and to developing suitable processes for producing these materials in cost-effective ways. Examples are developing materials for protection against chemical weapons, producing novel propellants and power sources, developing processes to protect materials against corrosion, and developing methods to demilitarize munitions. The ability to tailor material properties to meet DoD needs arises from an understanding at the molecular level of the relationships between structure and properties. This understanding of molecular processes and properties established through Chemistry research enables the design of components for military systems that exploit these properties for optimal performance.

Responsibilities for topics within the Chemistry area of the Basic Research Program are distributed in accordance with service mission considerations. These coordinated programs retain the responsiveness to pursue new scientific developments and service needs. The Army continues to emphasize systems related to chemical and biological defense (permeability, reactive and catalytic polymers) and to elastomers because of the heavy use of rubbery components in land vehicles. Important Navy areas of concentration include special considerations due to the marine environment, adhesion and surface properties relating to ship antifouling coatings, and novel cooling technologies and energetic materials (no civilian effort exists on which to depend). The Air Force emphasizes materials that maintain their integrity in extreme environments, corrosion chemistry related to aging aircraft, chemical lasers, and processes that affect operations in the atmosphere and in space. Topics of common interest continue to be: optical polymers for rapidly disseminating and displaying information to the warfighter; power sources for specific DoD applications; and forefront topics where specific applications remain the subject of speculation (e.g., nanostructures, biomimetics).

Chemistry research within the DoD Basic Research Program is divided into two major subareas: materials chemistry and chemical processes.

1. Materials Chemistry

Advanced materials play a key role in numerous DoD systems. Chemistry research focuses on the molecular design and synthesis of materials with properties that can be tailored to specific DoD requirements. Structure/property relationships are determined to enable the design of optimal material systems. Other widespread applications of Chemistry research include developing materials for marine and aerospace environments, strong and lightweight composite materials, electronic materials, semiconductors, superconductors, and barriers for chemical and biological weapons.

2. Chemical Processes

The ability to control the interaction between materials and their environments can be exploited for many DoD applications. Controlling friction and adhesion, corrosion, signatures, and the fate and transport of chemicals are some of the areas where this work impacts DoD operations. Molecular processes are being exploited to develop compact fuel cells as portable, clean power sources; to develop chemical lasers for directed-energy weapons; to control ignition and detonation of munitions; and to store energy in propellants.

Army research on polymers and elastomers continues to develop materials with properties tailored for chemical and biological defense needs. Ongoing research is addressing the destruction of munitions and the catalytic oxidation and hydrolysis of chemical agents and toxins, as well as techniques for detecting trace amounts of chemical hazards. The Army has consolidated and will lead the efforts in the area of highly branched dendritic molecules. Research on hydrogen, methanol, and liquid hydrocarbon fuel cells continues as a growing area led by the Army. The Navy continues its leadership in electrode interfaces and materials expected to develop medium- to large-scale energy conversion systems. The Navy leads work in development of carbon nanotube and organic composites for electronic and structural material applications. Activities in surface processes and interface reactivity for electronic device technologies operating in harsh environments are being pursued. The Air Force continues to develop new materials synthesis methods, particularly the novel work it is doing on inorganic polymers, which holds promise of a new class of versatile materials that operate in extreme environments. Air Force work to understand, detect, and prevent corrosion of aircraft is increasing. The Air Force is actively pursuing approaches to develop lightweight chemical laser systems. Common efforts within the SPG in chemical synthesis address energetic materials and supra-molecular chemistry for applications in biomimetics and detection systems. Research on optical polymers for information processing applications is continuing to make progress in meeting many DoD needs. Research in tribochemistry is developing an understanding of the role of surface chemistry in friction and wear, for example, to support synthesis of tailored lubricants.

Table IV–2 provides an outline of service-specific interests and commonality in this area.

Table IV–2. Service-Specific Interests and Commonality in Chemistry

Subarea	Army (A)	Navy (N)	Air Force (AF)
Materials Chemistry Theory Molecular design Synthesis and properties of compounds	Catalysts (chemical/biological warfare (CBW)) Elastomers Reactive polymers (CBW) Barrier/permselective polymers Dendritic molecules	Nanoelectronic materials Inorganic semiconductors Minimally adhesive surfaces Complex oxides Nanotubes/organic composites	Inorganic-based protective coatings and space materials Aircraft coatings Polymeric high-temperature materials
	Areas of Common Interest: nanostructures (A, N, AF); energetic materials (A, AF); power sources (A, N, AF); functional polymers (A, N, AF); sensors (A, N, AF); lubricants (N, AF)		
Chemical Processes Atomic and molecular energy transfer Transport phenomena Reactions Changes of state	Decon/demil chemistry CBW detection Organized assemblies Diffusion/transport in polymers Energetic ignition/detonation	Biomimetic catalysis (CBW) Combustion/conflagration in fuels Surface and Interface processes Self-assembled mesostructures Ion/charge transport Adhesion	Chemical lasers Atmospheric and space signatures and backgrounds Processing (ceramics, polymers, sol gels) Thin-film growth
	Areas of Common Interest: chemical dynamics (A, N, AF); tribochemistry (A, N, AF); sensors (A, N, AF); chemistry of corrosion & degradation (A, N, AF); power sources (A, N, F)		

C. MATHEMATICS AND COMPUTER SCIENCES

Research in Mathematics and Computer Sciences contributes analytical and computational tools in diverse areas with substantial military impact. This research strongly supports the *Defense Technology Area Plan* (Reference 10). Advances in materials, combustion and detonation, photonics, sensors, intelligent software agents, and battlefield decision aids, among others, depend on achievements in mathematics and computer science. For example, approaches to computer vision for automatic target recognition (ATR) require research in constructive geometry, numerical methods for stochastic differential equations, Bayesian statistics, probabilistic algorithms, and distributed parallel computation. The mathematics SPG plans and conducts a balanced program involving both need-driven and opportunity-driven topics.

The realism, interoperability, synchronization, and scaling behavior of modeling and simulation are vital for military needs. The design of intelligent agents, the foundations of heterogeneous and distributed databases, the design and evolution of software systems, and real-time algorithmic and architectural issues for battlefield decision aids are all important DoD areas of interest that involve mathematics and computer science in critical ways.

The services support basic research in mathematics on nonlinear dynamics and on multiscale phenomena. The results of this research are applicable both to the specific concerns of each service as well as to common issues. The Army leads in mathematics research pertinent to the development and performance of novel materials for advanced armor and antiarmor systems. The Navy leads in ocean modeling and wavelet-based image processing. The Air Force leads in control and guidance.

A major interest in computational mathematics is in adaptive methods. In operations research, the prime topic of DoD interest is mathematical programming and the modeling of discrete event systems, reflecting needs of all three services for improved algorithms for large, complex planning problems and logistics. The Air Force has the lead in compressible and hypersonic flow; the Navy, in nonlinear filtering (for target tracking) and incompressible flows (for hydrodynamic design); and the Army, in probabilistic methods for automatic/aided target recognition.

The diverse needs of the services, driven primarily by requirements associated with different platforms, are the foundation for the topical computer science areas pursued within each agency. For instance, while the Navy pursues novel computing concepts with potential to help the fleet accomplish its missions dependably, the Army is driven by requirements pertinent to development of the digital battlefield. Because of demanding computing-speed requirements for aerospace defense, the Air Force has the lead in parallel programming archetypes. In the area of intelligent systems, each of the services' research offices has considerable interest and activity. On the other hand, the virtual environments subarea is being pursued primarily by the Army and Navy to support a variety of combat simulation needs and battlespace management applications. Machine vision is pursued by all services to support reconnaissance and surveillance missions. However, the focus of this research differs significantly for each service due to the widely different regimes in which they operate (land, open ocean and littoral zones, the atmosphere and space).

1. Mathematics

Within the DoD Basic Research Program, research in Mathematics falls into three general subareas.

a. Modeling and Mathematical Analysis

The fundamental knowledge provided by research in this area increases DoD's ability to develop advanced ground vehicles, aircraft and naval vessels, energetic materials, delivery systems, radar, sonar, sensors and actuators, and other military equipment.

b. Computational Mathematics

Research in this area impacts DoD capabilities in ballistics, target penetration, vulnerability, ground vehicles, aircraft, naval vessels, combustion, detonation, and stealth technology.

c. Stochastic Analysis and Operations Research

Research in this area impacts DoD capabilities in design, testing, and evaluation of systems; decision making under conditions of uncertainty; logistics; and resource management.

2. Computer Sciences

Similarly, research in Computer Sciences falls in three general subareas.

a. Intelligent Systems

The fundamental knowledge provided by research in this area directly affects DoD capabilities in automated C^3I systems, guidance and control of semiautomated and automated platforms, ATR, and real-time warfare management decision aids.

b. Software

Research in this area influences DoD capabilities in automation, decision support, combat systems, warfare management systems, distributed interactive simulation, digitization of the battlefield, training, and man-machine interaction.

c. Architecture and Systems

This area affects DoD capabilities in warfare management, real-time data acquisition, training, C^3I, geographic information systems, ATR, system automation, distributed interactive simulation, and vulnerability and lethality analysis.

Table IV–3 provides an outline of service-specific interests and commonality in this area.

Table IV–3. Service-Specific Interests and Commonality in Mathematics and Computer Sciences

<table>
<tr><th>Subarea</th><th>Army (A)</th><th>Navy (N)</th><th>Air Force (AF)</th></tr>
<tr><td colspan="4">Mathematics</td></tr>
<tr><td rowspan="2">Modeling and Mathematical Analysis
Physical modeling and analysis</td><td>Mathematics of materials science
Reactive flows</td><td>Ocean modeling and mixing</td><td>Control and guidance
Nonlinear optics</td></tr>
<tr><td colspan="3">Areas of Common Interest: inverse problems (N, AF); multiscale phenomena (A, N, AF); nonlinear dynamics (A, N, AF)</td></tr>
<tr><td rowspan="2">Computational Mathematics
Numerical analysis
Discrete mathematics</td><td>Computational mechanics
Data representation
Discrete mathematics</td><td>Computational acoustics
Computational statistics
Computational logic</td><td>Computational control
Compressible and hypersonic flow</td></tr>
<tr><td colspan="3">Areas of Common Interest: adaptive methods (A, N, AF); computational electromagnetics (N, AF)</td></tr>
<tr><td rowspan="2">Stochastic Analysis and Operations Research
Statistical methods
Applied probability optimization</td><td>Statistical modeling
Simulation methodology
Nonlinear filtering</td><td>Random fields</td><td>Hybrid Systems
Combinatorial Search</td></tr>
<tr><td colspan="3">Areas of Common Interest: stochastic image analysis (A, N); stochastic partical differential equations (PDEs) (A, N); mathematical programming (A, N, AF); network and graph theory (A, N, AF); Nonlinear filtering (A, N)</td></tr>
<tr><td colspan="4">Computer Sciences</td></tr>
<tr><td rowspan="2">Intelligent Systems
Control
Learning
NLP
Motion planning
Virtual environments
Languages</td><td>Intelligent control
Natural language processing
Machine intelligence</td><td>Case-based reasoning
Machine learning
Motion planning</td><td>Intelligent real-time problem solving
Intelligent tutoring
Intelligent agents</td></tr>
<tr><td colspan="3">Areas of Common Interest: data fusion (A, AF); machine vision (A, N, AF); virtual environments (A, N); novel computing paradigms (A, N, AF)</td></tr>
<tr><td rowspan="2">Software
Software engineering
Software environments
Languages</td><td>Heterogeneous database
Formal languages
Automation of software development</td><td>Hard real-time computing
Structural complexity
Programming logic</td><td>Information warfare high-performance knowledge bases</td></tr>
<tr><td colspan="3">Areas of Common Interest: software environments (A, N, AF); programming languages (A, N, AF); formal design and verification (N, AF)</td></tr>
<tr><td rowspan="2">Architecture and Systems
Compilers
Operating systems</td><td>Scalable parallel combat models
Hybrid system architectures</td><td>Ultradependable multicomputing systems
Secure computing</td><td>Distributed computing for command, communications, and control (C^3)</td></tr>
<tr><td colspan="3">Areas of Common Interest: operating systems (A, N, AF); man–machine interface (A, N)</td></tr>
</table>

D. ELECTRONICS

Electronics is considered a dominant force multiplier in DoD systems. Basic research in Electronics supports all elements of the JWSTP and is both need and opportunity driven. The Electronics SPG plans and conducts a forward-looking, well-integrated research program that addresses many of the currently defined mission deficiencies and operational requirements, including aiming and position accuracy of weapons, all-weather surveillance and mobility, unmanned robotic vehicles and aircraft, real-time global surveillance, and reliable (minimum downtime) global and mobile wireless communications as needed for information dominance and network-centric warfare. These requirements are driven by affordability and a continuing need for operational superiority. Affordability includes the influence of size, weight, and power on the overall cost. Operational superiority requires systems possessing higher accuracy and vastly greater information throughput capacity to influence real-time situation assessment, or systems performing autonomously over land, at sea, or in the air or space.

The Basic Research Program in Electronics has established a national leadership position and has initiated, advanced, exploited, and leveraged research results in many fields that impact technologies of military importance. Representative examples are research efforts on infrared detectors and lasers for both tactical and strategic applications; wide-bandgap semiconductor research that is critical for high-temperature engine controls, efficient ultraviolet detectors, and high-power radio frequency (RF) active aperture arrays and shipboard switching devices; 100-GHz logic for digital RF and beamsteering; RF and optical computing devices needed to achieve major weight/size reductions in air and spacecraft signal processors; and mobile wireless communications and networking for the highly dynamic network topologies of the battlespace. DoD basic research in Electronics is distributed over the services in a manner that avoids duplication and maximizes benefits to specific service mission requirements. Army research areas are closely coupled to Army mission requirements for ground vehicles and soldier support; Navy programs are driven by considerations derived from multifunctional RF, ocean, and submarine operational needs; the Air Force research efforts are dictated by requirements for high-performance aircraft and space platforms. In addition to service-specific programs, the Electronics SPG plans for multiservice and multidisciplinary efforts to more effectively focus resources on recognized high-priority DoD topics.

The DoD Basic Research Program in Electronics is divided into three subareas: solid-state and optical electronics, information electronics, and electromagnetics.

1. Solid-State and Optical Electronics

Research in solid-state and optical electronics will provide the warfighter with novel or improved electronic and optical hardware, including nanoelectronics for surveillance, target acquisition, tracking, electronic controls, radar and communication, displays, data processors, and advanced computers. Research in solid-state electronics emphasizes topics of limited commercial interest such as radiation-hardened, low-power, low-voltage applications for soldier or space support; ultra-high-frequency devices to be applied in secure communication, remote detection of chemical or biological agents, or radar; versatile, wideband, multifunctional RF technology; or ultrafast, robust building blocks for future generations of efficient, dedicated supercomputers. Optical electronics, including photonics, takes advantage of the very high transmission bandwidth and aims at massive optical storage and parallel channels as critical building blocks of photonic computation. Other optical research is directed to multifunction IR and UV devices for target and threat detection.

2. Information Electronics

Basic research in information electronics will push the performance envelope for wireless communications and decision making by advancing mobile wireless networking, simulation and modeling, coding, digital signal processing, and image/target analysis and recognition. Research in information electronics is dedicated to signal processing for wireless applications and image recognition and analysis. Coding schemes for secure communication and robust communication networks are being investigated. Unique cellular arrays are being investigated for image processing to bypass software and algorithm bottlenecks. Optimum control of distributed information processing and transmission is also receiving substantial attention. Innovative approaches to modeling and simulation of devices and circuits are being pursued. Modeling and sensor fusion, as well as control and adaptive arrays, are also being emphasized.

3. Electromagnetics

Progress in electromagnetics will advance DoD capabilities in signal transmission and reception such as found in radar, high-power microwaves, or secure communications in built-up areas. The electromagnetics research program is focused on fundamentals of antenna design, dispersion-free beamsteering, scattering and transmission of EM signals, vacuum electronics modeling and simulation, and efficient and low-energy RF components for use predominantly in multifunctional and wireless applications. Computational electromagnetics is receiving strong emphasis, along with novel approaches to time-domain modeling of electromagnetic wave generation, transmission, and propagation. A substantial part of the program is focused on modeling of millimeter-wave phenomena by optical means. New adaptive, reconfigurable RF radio/sensor concepts are also being explored.

A more detailed outline of service-specific interests and commonality in this area is given in Table IV–4.

Table IV–4. Service-Specific Interests and Commonality in Electronics

Subarea	Army (A)	Navy (N)	Air Force (AF)
Solid-State and Optical Electronics Detectors Lasers Superconductors Nonlinear circuits	Infrared (IR) and ultraviolet (UV) detectors Power switches Terahertz electronics Low-power and low-voltage analog electronics	Wide-gap semiconductors Magnetic thin films All-digital RF electronics Magneto-electronics 6.1-angstrom materials	Radiation-hard electronics Nonlinear optical materials High-temperature electronics
	Areas of Common Interest: lithography (A, N); quantum transport (A, N); nanoscale and mesoscale electronics (A, N, AF); heterostructures (A, N, AF); multifunctional devices and micro-optics (A, N, AF); device reliability (N, AF); superconductors (N, AF); IR detector materials and IR lasers, (N, A); hyperspectral imaging (A, N, AF)		
Information Electronics Modeling and Simulation Communications Processing and Data Fusion	Mobile, wireless multimedia distributed communications IR target recognition and image analysis Energy efficient digital signal processing	Sensor array processing Distributed networks Soft/fuzzy logic/neural networks Reliable, fault-tolerant very-large-scale integration (VLSI)	None
	Areas of Common Interest: modeling/simulation of circuits, devices, and networks (A, N); sensor fusion (A, N, AF); digital signal processing (A, N, AF); target acquisition (A, AF); adaptive array processing (A, N, AF)		
Electromagnetics Antennas Transient sensing Tubes	Wireless and radar propagation Advanced MMW circuit and antenna integration Mobile tactical wireless and printed antennas	Dispersion-free beamsteering	Transient electromagnetics Secure propagation Distributed aperture radar
	Areas of Common Interest: integrated transmission lines (A, N, AF); EM numerical techniques (A, N, AF); discontinuities in circuits (A, N, AF); EM scattering (N, AF); vacuum electronics (N, AF); optical control of array antennas (A, N, AF); power-efficient RF components (A, N, AF); adaptive arrays (A, N, AF)		

E. MATERIALS SCIENCE

Advanced materials research being conducted as part of the DoD Basic Research Program includes both need-driven and opportunity-driven elements that will impact virtually all DoD mission areas in the future. The Materials Science SPG plans and conducts an aggressive, integrated research program that is leading to new classes of materials possessing, increased strength and toughness, lighter weight, greater resistance to combinations of severe chemical and complex loading environments, and improved optical, magnetic, and electrical properties. These advances are focused on meeting the Joint Chiefs of Staff warfighting needs by providing access to higher performance and superior weapon systems together with improved readiness, decreased need for logistic support, increased reliability, and lower lifetime cost.

Navy programs are driven by operational considerations such as ocean surface and subsurface vehicle designs as well as naval air, space, and missile system parameters. Air Force research efforts are dictated by requirements for high-performance aircraft and space platforms. Army research areas are closely coupled to Army mission requirements for armor/antiarmor systems, advanced rotorcraft, ground vehicles, missiles, and projectiles. In certain areas of materials research, more than one service has a vested interest in supporting programs. These areas of commonality involve large, diverse, and long-term multidisciplinary efforts. Such efforts are jointly planned through the Materials Science SPG to maximize return on investment. For example, the area of tribology has the potential to impact the operational service life of guns, engines, and aircraft (among many other military systems). The tribology programs were planned with the Army sponsoring work on ion beam engineering/surface modification, the Navy supporting computational and experimental approaches for understanding wear surfaces and interfaces, and the Air Force focusing on failure diagnostics for aging aircraft.

The DoD Basic Research Program in Materials Science includes two subareas: structural materials and functional materials. Research in both subareas includes elements of synthesis, processing, structure, properties, theory, and modeling.

1. Structural Materials

Research in structural materials is needed to satisfy operational requirements of DoD systems such as armor and penetrators; durable, high-temperature components of high-performance engines used in hypersonic air vehicles, and high-performance, low-cost spacecraft materials; and lightweight, tough, corrosion-resistant hulls of naval ships. Structural materials of principal interest are metallic materials, ceramics, composites, and polymers. The structural aspects pertain primarily to service under mechanical loads. Research is focused on designing and processing advanced materials to achieve higher performance and improved reliability at lower costs, developing new materials with unique microstructures, providing improved understanding of material behavior under a variety of complex loading and environmental conditions, optimizing interface chemistry and mechanics, and developing innovative nondestructive techniques for characterizing materials and investigating the interrelationships that couple material processing and performance. Some of the research areas of growing importance pertinent to these thrusts include computational design, aging systems, biomimetics, and nanoscience. The area of aging systems is of particular concern for all three services in that research results may provide new opportunities for affordably maintaining and upgrading aging assets. Each of the services is investing in multidisciplinary research focused on meeting this long-term need. Research is focused in the areas of corrosion and degradation, failure mechanisms, and life prediction and life management, with each service concentrating on the special materials and structural aspects of its unique platforms and collaborating in more generic areas.

2. Functional Materials

DoD systems that are affected by research in functional materials include a host of electronic devices and components; mobile and fixed electro-optical communication equipment; radars, sonars, and other detection devices; displays; readers; and power-control devices. Research in this area is focused on understanding and controlling materials processes to achieve affordable products and reliable performance, attaining materials-by-design capability to provide new materials with unique properties, investigating the principles of defect engineering, and exploring the potential of nanoscience. For example, in the area of smart systems, novel material approaches that include very high strain single-crystal piezoelectrics ($PbMgNBO_3$–$PbTiO_3$) and magnetic materials (Ni_2MnGa) are being pursued. These materials offer new opportunities for dynamic control of structures in advanced aircraft, rotorcraft, ships, and submarines. Further, such materials will enable the development of very sensitive devices for perimeter sensing, sonar systems, and mine detection. Areas of growing importance include nanoscience, smart systems, and thermoelectrics. For example, in the area of thermoelectrics, novel material approaches that include lead telluride (PbTe)-based superlattices, skutterudites, and organic composites are being pursued. These materials offer new opportunities for low-temperature cooling of night-vision equipment and electronics, and for high-temperature applications for shipboard cooling and power generation.

An outline of service-specific interests and commonality in this area is included in Table IV–5.

Table IV–5. Service-Specific Interests and Commonality in Materials Science

<table>
<tr><th>Subarea</th><th>Army (A)</th><th>Navy (N)</th><th>Air Force (AF)</th></tr>
<tr><td rowspan="2">Structural Materials
Synthesis
Processing
Theory
Properties
Characterization
Modeling</td><td>Manufacturing science (land/rotorcraft systems, armaments)
Armor/antiarmor materials
Diesel engine materials
Gun tube liner materials</td><td>Marine corrosion, oxidation, and fatigue
Advanced materials for ships and submarines
Acoustically damped structures
Ultrafast low-cost composite process</td><td>High-temperature fatigue and fracture
Airframe and engine materials
Aging aircraft
Functionally graded materials
Space plane, spacecraft, and launch vehicle materials
Material properties integration</td></tr>
<tr><td colspan="3">Areas of Common Interest: advanced composites (A, N, AF); adhesion/joining (A, N); tribology (A, N, AF); ceramics (A, N, AF); intermetallics (N, AF)</td></tr>
<tr><td rowspan="2">Functional Materials
Synthesis
Processing
Theory
Properties
Characterization
Modeling</td><td>Defect engineering
Optical components
IR detector materials
CBD materials
Smart materials</td><td>Ferrite films
Ferroelectrics
Dielectrics for passive components
Acoustics/active materials
Superconductivity</td><td rowspan="2">(Topics addressed under Chemistry, Electronics, Physics, and Mechanics basic research areas)</td></tr>
<tr><td colspan="2">Areas of Common Interest: optoelectronics (A, N); magnetic materials (A, N)</td></tr>
</table>

F. MECHANICS

DoD-sponsored basic research in Mechanics represents the major national effort in this field. The overall scientific goal is to understand and control the response of complex phenomena for various military applications, including combat vehicles and weapon systems. Such understanding results in new capabilities for designing weapons, platforms, and subsystems that meet desired performance levels, offer enhanced survivability, and have predictable costs. DoD is experiencing an increasing need for these advanced capabilities because (1) modern demands for simulation-based design data to support acquisition decisions place a premium on the ability to accurately forecast system capabilities, and (2) longer service lives of major system acquisitions increase demands for major performance improvements with predictable affordability constraints.

Mechanics, as an engineering science, is closely tied to the issue of complexity. Complexity manifests itself in several ways, such as the extremely large range of scales present in a phenomenon, or the plethora of simultaneous interactions that govern its dynamics. Research in Mechanics is focusing on understanding relationships between microscale phenomena and macroscale response; submicroscale mechanical response devices for obtaining service-history data; inventing new concepts for predicting and controlling strongly nonlinear/dynamic phenomena; conducting interdisciplinary work with synergistic ideas from analysis, simulation, and diagnostics; and determining the appropriate level of complexity relevant to engineering. These characteristics, alone or in combination, are present in all DoD research in Mechanics. Major research tools include modeling based on new concepts in analysis and optimization; simulation, often taxing the largest of modern parallel supercomputers; and diagnostics, which measure spatial-temporal variations of multiscale phenomena.

Mechanics research supported by the DoD Basic Research Program can be conveniently divided into three general subareas: solid and structural mechanics, fluid dynamics, and propulsion and energy conversion. Each service performs research responsive to its particular system drivers. In a number of areas, the services have common interests. In general, each service performs research in an area of commonality, with specific nonoverlapping technology targets. For example, in structural dynamics and smart structures, the Army emphasizes stability and control of rotorcraft structures, the Navy focuses on underwater explosion effects and structural acoustics, and the Air Force targets fixed-wing aeroelasticity and engine dynamics.

1. Solid and Structural Mechanics

Research in this area deals with the identification, understanding, prediction, and control of multiscale phenomena that affect the properties and reliability of modern DoD structures. Such phenomena range from fracture and fatigue initiated at micromechanical levels to multiple-scale interactions that need to be quantified in order to optimize the dynamics of complex structures. Fracture alone costs DoD billions of dollars every year. Emphasis is in integrating knowledge from micro to macro level and on macro-optimization. Research on “smart” structures integrates actuators, sensors, and control systems into the structure to accomplish damage control, vibration reduction, and reconfigurable shapes (e.g., smart helicopter rotor blades). Opportunities exist for optimizing lift-to-drag ratio, increasing lift, expanding the flight envelope, and reducing required installed power on DoD air vehicles. Solid mechanics research addresses finite deformation and failure mechanisms, penetration mechanics, and computational mechanics.

Reliability of ship structures, underwater explosion effects, structural acoustics and dynamics, shock isolation/vibration reduction in machinery, and noise control are addressed. A growing area of interest is the micromechanics of semiconductors, interconnects, and packaging for power-electronic building blocks (PEBBs) used for power distribution. High-cycle-fatigue issues are addressed by new multidisciplinary research in structures, materials, aerodynamics, and control of turbomachinery. The anticipated products are physics-based models for response prediction, an enhanced understanding of unsteady and transient engine behavior, and robust active control.

2. Fluid Dynamics

The design, performance, and stealth of DoD weapons, platforms, and subsystems depend on tailoring the distributed fluid mechanical loads that control their dynamics. Modern supercomputers, whole-field laser diagnostics, sophisticated turbulence models, and microelectromechanical actuators are used, alone or in combination, to produce validated prediction/control methods. Central to fluid dynamics research is the understanding, prediction, and control of turbulent flows with high Reynolds numbers. Such flows can be rotorcraft wakes, unsteady flows around maneuvering fighters, or multiphase flows around marine propulsors. Increased attention is being given to the coupling of helicopter rotor aeroacoustic fields and structural deformation, the understanding of compressibility, and full-scale Reynolds-number effects in aerodynamics and hydrodynamics. Simulations of high-speed flows in complex configurations relevant to hypersonic vehicles are being pursued, with emphasis on integrated approaches to inlets, supersonic combustion, and nozzles. Interdisciplinary research explores intelligent flow control strategies using microelectromechanical systems (MEMS) for thrust vectoring, high lift, drag reduction, and noise/signature reduction. An important new focus involves simulations of free-surface/two-phase flows around surface ships, understanding and predicting the behavior of maneuvering undersea vehicles, and exploring supercavitation phenomena for high-speed undersea weapons.

3. Propulsion and Energy Conversion

Research in this area is crucial to the performance and stealth of DoD weapons or platforms. The research is inherently and strongly multidisciplinary, combining knowledge from chemical kinetics, multiphase turbulent reacting flows, thermodynamics, detonations, plasmas, and control. Increasing emphasis and growth expectation are being given to active sensing, actuation, and control for engines, and integration into an intelligent engine model; high-pressure kinetics; and combustion diagnostics. Another research focus involves synthesizing new energetic materials/fuels, characterizing their behavior, and controlling their energy release rates for specific DoD weapon applications. Research on the physical, chemical, and material interactions in solid propellants—at realistic pressure environments—addresses their combustion mechanisms. Active combustion control is being pursued for tailoring tactical missile motor behavior and compact shipboard incinerators. High-performance aircraft require engines with high operating temperature and pressure. Research to achieve more efficient and durable combustion dynamics and high-thermal-capability (supercritical) fuels is being conducted.

Service-specific interests and commonality in this area are cited in Table IV–6.

Table IV–6. Service-Specific Interests and Commonality in Mechanics

Subarea	Army (A)	Navy (N)	Air Force (AF)
Solid and Structural Mechanics Structural dynamics Composites Aeroelasticity Acoustics	Finite deformation, impact, and penetration	Structural acoustics Thick composites Micromechanics of electronic devices and solids	Hypersonic aeroelasticity Mechanics of high-temperature materials Particulate mechanics
	Areas of Common Interest: structural dynamics and control (A, N, AF); damage and failure mechanics/quantitative nondestructive evaluation (A, N, AF); smart structures (A, N, AF)		
Fluid Dynamics Aerodynamics Turbulence Unsteady flow	Rotorcraft aerodynamics Rotorcraft aeropropulsion Projectile aeroballistics	Free-surface phenomena Hydrodynamic wakes Hydroelasticity and hydroacoustics	Turbomachinery aerothermodynamics Fixed-wing aerodynamics Hypersonic aerothermodynamics
	Areas of Common Interest: unsteady separated flow (A, N, AF); turbulence (N, AF)		
Propulsion and Energy Conversion Air-breathing Rocket Explosives	Reciprocating engines Gun propulsion Small gas turbines	Underwater propulsion Missile propulsion Explosives	Large gas turbines Supersonic combustion Spacecraft and orbit propulsion
	Areas of Common Interest: high-energy materials combustion/hazards (A, N); soot formation (A, N, AF); turbulent flows (A, N, AF); spray combustion (A, AF)		

G. TERRESTRIAL AND OCEAN SCIENCES

The DoD requirement for a core competency in Terrestrial and Ocean Sciences arises from the fact that the oceans and their borders are the Navy and Marine Corps' main operating environment, while the Army operates on the land surface and has mission interests with the Navy and Marine Corps in joint logistics-over-the-shore (JLOTS) and coastal engineering. The impact that these physical environments have on virtually every aspect of Army, Navy, and Marine Corps activity requires a robust competency in Terrestrial and Ocean Sciences. The nature of the specific DoD applications for these research results distinguishes the details of these research areas from more general research in land/ocean by other agencies.

1. Terrestrial Sciences

DoD research in Terrestrial Sciences encompasses study of the broad spectrum of land-based phenomena that affect the Army. In particular, this research is concerned with the impact of the surface and near-surface environment on Army activities and is directed at those particular elements that may have significant bearing on the planning, rehearsal, and execution of military campaigns. Additional aspects of importance are the management and stewardship of Army installations, particularly as regards the sustainability of Army training and testing, and the remediation of Army contaminated sites. Current research comprises work in three interrelated subareas:

a. Terrain Properties and Characterization

An ability to understand and utilize the variable topographic and physical characteristics of the landscape is critical to mobility/countermobility, communication, survivability, and troop and weapon effectiveness. Thus, a foundation to enhanced battlefield capability for the force-projection, precision-strike Army of the 21st century will be superior knowledge of terrain and the ability to incorporate that knowledge into Army doctrine, systems development, and testing/training-to-mission planning and rehearsal, field operations, and logistics. Research in terrain characterization is directed toward fostering the development of advanced geoscience capabilities that will yield a better understanding and utilization of information about topography, natural terrain features, environmental characteristics, man-made objects, and urban environments. A major goal of this effort is a capability for the rapid post-acquisition generation, analysis, and utilization of remotely sensed terrain data about short-term battlefield conditions and dynamics. This force-multiplying capability will enhance a commander's ability to visualize a battlefield at multiple resolutions and execute combat operations using an efficient decision-making cycle much more rapidly and effectively than an adversary.

b. Terrestrial Processes and Landscape Dynamics

Improved understanding of terrestrial processes affecting Army operations in different physical environments is the focus of this area. New approaches to the measurement and constitutive description of surface material properties and processes are needed to treat the complex and generally nonlinear dynamics governing the surficial environment, which typically operate over a wide range of often discontinuous spatio-temporal scales and are extremely difficult to characterize and quantify. Explicit consideration of these processes and their interactions will lead to critically needed improvements in the ability to predict environmental effects on Army operations, new approaches to Army testing and training land sustainability, and the cost-effective remediation of environmental contamination.

c. Terrestrial System Modeling and Model Integration

The ultimate objective of the efforts described above to characterize the natural environment and study surficial processes is to develop or enhance integrated system models and simulators. Research in this area is aimed at integrating advances in fundamental theory and process understanding into existing environmental process and material behavior models. Environmental information and individual numerical models will be integrated into systems models to develop the ability to simulate and forecast system and unit performance, such as a capability to effectively model and predict vehicular mobility or nearshore behavior in real time under dynamic environmental and battlefield conditions.

2. Ocean Sciences

Important phenomena and parameters in the Ocean Sciences include tides, currents, temperature and salinity of the water column, surface and internal waves, ocean fine structure, surf, optical properties, bubbles, and biological and chemical contents. The dominant area of scientific and technological advance is in nowcasting and forecasting the ocean and its acoustic, optical, and electromagnetic features from the bottom to the surface. The domain for this advance extends from the open ocean to the beach. There are two foci in the integrated DoD research topic of battlespace environments, of which the ocean environment is a part: environmental characterization (and prediction), and the effects of the environment on sensors, systems, tactics, and weapons. Current DoD research falls into three interrelated subareas:

a. Oceanography

The fundamental knowledge provided by research in oceanography impacts naval capabilities to operate in the ocean, and the ability to use its sensors and weapons effectively. Both Army and Navy/Marine Corps capabilities in the coastal and beach regimes are addressed. Kilometer or coarser resolution thermal structure characterizations may be adequate to resolve the ocean scales to support low-frequency active acoustic systems in the open ocean. However, the littoral zones of the world (e.g., marginal shelves, shallow water coastal regions) require much finer resolution than that developed for open ocean models in order to nowcast/forecast the four-dimensional ocean environment in support of operations such as amphibious assault, special operations, and mine countermeasures (MCM). Recent accomplishments include the discovery of ultra-thin layers of oceanic biological activity materially affecting undersea optical surveillance; and development of a full Boltzmann shallow-water wave model, which impacts the accuracy of coastal wave predictions in support of JLOTS and expeditionary warfare.

b. Ocean Acoustics

Oceanography affects the Navy's capabilities to detect, classify, and neutralize undersea enemy systems and activities. The ocean is effectively transparent to sound propagation, so fundamental knowledge of ocean acoustics is key to system design, operating strategies, and tactical decisions. The Navy has identified ocean acoustics as an area of national responsibility for Navy investments. Recent accomplishments include identification of the importance of range dependence for shallow-water acoustics, providing enhanced detection and classification of diesel submarines in coastal environments; development of an efficient poro-elastic numerical code for high-frequency acoustics, critical to effective mine hunting and torpedo guidance in shallow water; and identification of internal waves as significant scatterers for long-range acoustic propagation, affecting acoustic systems design to regain acoustic superiority in deep water.

c. Ocean Geophysics

This area affects both Navy and Army capabilities to work in the ocean and at its boundaries, and ongoing research provides part of the essential knowledge base required by the other two subareas. Recent accomplishments include the development of the sequence stratigraphic methodology for identifying sedimentary regimes, which provides a zero-order statement of bottom sediments in denied areas to support shallow-water antisubmarine warfare (ASW) and mine-hunting operations; and development of techniques for combining light detection and ranging (LIDAR) bathymetry with hyperspectral images to infer bottom materials and depth, allowing airborne and satellite remote sensing estimation of bottom type and characterization in support of MCM and expeditionary warfare.

Service-specific interests in this area are described in Table IV–7.

Table IV–7. Service-Specific Interests in Terrestrial and Ocean Sciences

Subarea	Army	Navy	Air Force
Terrestrial Sciences			
Terrain Properties and Characterization	Terrain data generation and analysis Properties of natural materials Site characterization	Continental terraces	None
Terrestrial Processes and Landscape Dynamics	Surficial processes and geomorphology Hydrometeorology and hydrology Coastal erosion and engineering Groundwater flow and mass transport	Near-shore sediment processes	None
Terrestrial System Modeling and Model Integration	Tactical mobility and logistics-over-the-shore (LOTS) Sustainable testing and training lands Contaminant remediation		None
Ocean Sciences			
Oceanography	None	Physical, chemical, biological, optical modeling, and prediction	None
Ocean Acoustics	None	Shallow-water acoustics High-frequency acoustics Long-range propagation	None
Ocean Geophysics	LOTS Coastal engineering Coastal erosion	Continental terraces Sediment processes	None

H. ATMOSPHERIC AND SPACE SCIENCES

Research in Atmospheric and Space Sciences develops the basic technical foundations in these areas primarily for use in many applications important to DoD. Research in meteorology (dynamical, physical, and modeling), space science (ground-, air-, and space-based), and remote sensing (active and passive) is conducted to support a broad range of DoD interests and activities. The products of these 6.1 basic research efforts and accompanying 6.2/6.3 work undergo transition to operational commands for use in weapon and surveillance platforms; planning of peacetime and warfighting operations; live and simulated training; and forecasting, mitigation, and modification of the battlespace environment.

For DoD to plan and conduct a comprehensive program of research across the broad spectrum of air and space science topics, however, is fiscally and technically not feasible. Therefore, DoD provides products to other agencies and cooperates with them to enhance the knowledge. Examples of cost-sharing and leveraging of work by other agencies include tropical storm research (Office of Naval Research (ONR) and the National Oceanic and Atmospheric Administration (NOAA)), high-resolution modeling (ARO, ONR, the National Science Foundation (NSF), and NOAA), atmospheric aerosols (ONR, Army Research laboratory (ARL) and NASA), and boundary layer modeling (ARO and NOAA). In the international community, DoD sponsors scientific conferences such as the DoD Battlespace Atmospheric and Cloud Impacts on Military Operations (BACIMO) as well as focused scientific workshops. These conferences attract government, university, and industry researchers from all over the world and help to ensure that this area of DoD basic research is highly leveraged and well coordinated with others in the field.

Mission assignments for each service serve as focal points for supported research. For example, the Army emphasizes research in continental boundary layer dynamics, remote sensing of atmospheric state and content, and atmospheric effects on sensor systems. The Navy has responsibility for global- and theater-scale meteorology focused on the marine environment, including tropical cyclones, marine cloud processes, air–sea interactions, and coastal zone predictions. The Navy space program emphasizes space-based atmospheric physics, while the Air Force counterpart tends to emphasize remote sensing of space objects, detection and tracking of missiles, and on-orbit satellite operations and survivability. If appropriate, interservice collaborations and many complementary research programs are used when common interests are served.

Basic research in Atmospheric and Space Sciences comprises work in three subareas: meteorology, space science, and remote sensing.

1. Meteorology

In many military operations, weather determines the order of battle and meteorology is its associated force multiplier. Safety of operations, logistical planning and execution, deployment of forces in and out of theater, and sensor and weapon performance are all influenced by weather conditions. The DoD's atmospheric research effort seeks to provide the basic understandings of global and theater weather needed to construct reliable prediction models used by operational commands. Understanding the basic nature of atmospheric turbulence and cloud boundary layers affects the ability to predict the transport and diffusion of airborne effluents, aerosols, heat, and moisture. For blue-water operations, special attention is directed toward understanding the behavior and evolution of tropical cyclones in general and in the Western Pacific in particular, where DoD has the lead forecast responsibility for the United States. Plans are to improve our knowledge about motion (track), structure (size), and intensity (wind speed) of these important phenomena. The research program balances theoretical modeling, analytical case studies, and experimental observations while exploring the limits of forecast predictability. The overall goal of these research efforts is to provide the highest quality mission-tailored weather information, products, and services to our nation's combat forces in peace and war—anytime, anyplace.

2. Space Science

As demonstrated during recent and current operations, U.S. forces are increasingly dependent on the capabilities of DoD space assets. GPS navigational capabilities, critical in high-technology warfare, are the direct result of long-term and ongoing basic research in precision timekeeping. Precision time-interval and time-transfer technology are also required for precise targeting and synchronization of secure communications and other systems. Ionospheric and upper atmospheric neutral density research will address needs for improved GPS accuracies, precision geolocation of RF emitters, and RF communications. A new naval optical interferometer may provide positional accuracies of astronomical sources below the milliarc-second level. These advances, combined with improved astrometric reference frames and continuing improvements in compact electronics, will support operational requirements for systems with increased precision guidance and autonomous satellite navigation. The high bandwidth and secure communications features of the Milstar satellites are the result of large 6.1 investments in radiation-hardened electronics, broadband communications, ionospheric specification, and power generation. Continuing efforts in these areas, coupled with ongoing developments in mobile wireless band communications, will result in a new generation of smaller, lighter, and more affordable satellites.

The next generation and block upgrades of DoD missile early-warning satellites—the Space-Based Infrared System (SBIRS)—will not be possible without continuing investment in focal plane technology, onboard signal processing capabilities, and the ability to acquire and track very dim targets against highly cluttered backgrounds. The potential ability to exploit basic understandings of plume signatures and varying background radiance in the design of spectrally agile electro-optical sensor systems may even enable the detection of cruise missiles from space-based platforms. Solar and heliospheric research is directed toward understanding the mechanisms for generation of solar extreme electromagnetic fluxes, solar flares, coronal mass ejections, and the propagation of these phenomena from the sun through the magnetosphere and ionosphere. The resulting ionospheric variability affects RF communications over a very wide range of frequencies. A better understanding of solar and space physics, and the ability to predict sooner the effect of solar activity, will enable commanders to switch to the other assets and to turn off those systems susceptible to damage, temporary or permanent, until the space environment has returned to acceptable limits. Upper atmospheric neutral density is also a function of solar activity, and future research will result in improved specification of satellite drag, orbital tracking, and vehicle reentry—providing the U.S. Space Command greater capability to maintain and upgrade the Space Object Catalog.

3. Remote Sensing

Remote sensing characterizes environmental parameters and target signature characteristics critical to the performance of surveillance, acquisition, tracking, and home-to-kill sensors and weapons. It also supports critical needs in chemical/biological warfare. In meteorology, wind profiler technology will provide details regarding the fine structure of wind, temperature, humidity, and aerosols within the atmospheric boundary layer. Of special importance is the ability to model and predict marine refractivity profiles and surface base ducts. The development of the Airborne Laser is highly dependent on basic research directed toward measuring and mitigating the effects of natural and induced atmospheric turbulence. Remote sensing for missile warning and subsequent track and kill will be greatly enhanced with the planned development of hyperspectral imagery techniques and associated automatic target recognition algorithms. The ability to use space-based electro-optical sensors to see through the lower atmosphere and clouds is increasingly important as the theater ballistic missile threat requires better all-weather capability and improved warning times for cueing tracking sensors. The threat of chemical and biological agents against military and civilian populations has led to increased emphasis on the development of biosensors with very special responsivities.

Service-specific interests and commonality in this area are presented in Table IV–8.

Table IV–8. Service-Specific Interests and Commonality in Atmospheric and Space Sciences

<table>
<tr><th>Subarea</th><th>Army (A)</th><th>Navy (N)</th><th>Air Force (AF)</th></tr>
<tr><td rowspan="2">Meteorology</td><td>Continental boundary layer
Transport and diffusion
Chemical/biological defense
Clouds and obscurations</td><td>Marine boundary layer
Maritime and coastal meteorology
Major storms, worldwide, with particular emphasis on tropical cyclones
Synoptic to mesoscale prediction</td><td>None</td></tr>
<tr><td colspan="3">Areas of Common Interest: coherent structures (A, N); subgrid scale parameterization (A, N); large eddy simulation (A, N); nested models of all scales (A, N); surface energy balance (A, N); cloud formation and processes (A, N) data assimilation (A, N)</td></tr>
<tr><td rowspan="2">Space Science</td><td rowspan="2">None</td><td>Precision time
Space-based solar observation
Wave–particle interactions
Astrometry</td><td>Ground-based solar observations
Energetic solar events
Ionospheric structure and transport
Optical characterization</td></tr>
<tr><td colspan="2">Areas of Common Interest: neutral density (N, AF); ionospheric C^3I impacts (N, AF); celestial background (N, AF); geomagnetic activity (N, AF)</td></tr>
<tr><td rowspan="2">Remote Sensing</td><td>Fine-scale measurement of wind, temperature, and humidity fields and fluxes
Chemical/biological detection and identification
Atmospheric acoustics</td><td>Marine refractivity profiles, especially in coastal zone
Aerosol modeling
Convective and stratus clouds
Air–sea interfacial flow</td><td>None.</td></tr>
<tr><td colspan="3">Areas of Common Interest: atmospheric profiles of temperature, humidity, winds, aerosol concentration (A, N); aerosol effects (A, N); atmospheric transmission(A, N); radiative energy transfer (A,N); contrast transmission (A, N).</td></tr>
</table>

I. BIOLOGICAL SCIENCES

Research in Biological Sciences provides the fundamental understanding required to use biological processes and techniques for producing novel materials and processes having important military applications. Major goals are to increase affordability by reducing maintenance and synthetic processing costs; to inhibit or prevent the deleterious effects of chemical, biological, and physical agents from interfering with military warfighting and peacekeeping operations; and to ensure that force health protection and safety standards are based on solid scientific evidence. With the exception of biomedical programs, which are closely coordinated through the Armed Services Biomedical Research Evaluation and Management (ASBREM) Committee, a single service now conducts the basic research for all three services in areas where it is the technology leader for related 6.2 or 6.3 programs, or where that service has the largest investment and program expertise. The Army is the DoD executing agency for chemical and biological defense technology, and ONR and AFOSR rely on the results of Army-executed research in this area in meeting their own specific needs. The Air Force was designated through Reliance agreements to host the Tri-Service Toxicology Center at Armstrong Laboratory at Wright–Patterson AFB, Ohio as well as co-located S&T programs in nonionizing radiation and laser radiation bioeffects at Brooks AFB. The Navy is the only service that supports work in the marine environment.

DoD basic research in Biological Sciences comprises three major subareas: molecular/cellular, systems/organisms, and biomedical.

1. Molecular/Cellular

Basic research on antibodies, characterization of surface biomolecular interactions, receptors, and cell-based sensing has enabled the development of biochemical detector technology that has, in turn, provided the U.S. military with its first automated capability for detecting biological agents. Meanwhile, ongoing research promises to improve greatly on the selectivity component of future detectors, enhancing their capability to warn of threats from biological agents present in battlefield, counterterrorism, or counterproliferation scenarios. Likewise, research on olfactory sensing offers novel biologically inspired approaches for the design and eventual production of engineered systems capable of detecting trace amounts of explosives and toxic chemicals. In addition, this research will provide the military with unique advanced capabilities for sensing contamination of food, clothing, material, the individual warfighter, and the environment.

2. Systems/Organisms

Exposure of the warfighter to hazardous military chemicals (e.g., fuels and propellants) and to novel forms of electromagnetic radiation (e.g., laser pulses and high-power microwaves) can negatively impact military missions and result in serious long-term costs for DoD. The capability to develop and use nontoxic military agents will promote health and enhance the performance of the warfighter. Studies are ongoing to understand mechanisms by which these novel military agents may produce deleterious biological effects and to explore safe exposure levels. Research in this area will enable the development of scientifically derived safety standards, the design of protective equipment, and the improvement of experimental and computational approaches for rapidly assessing toxic properties of future agents. Recently, studies exploring the interaction of single ultrashort laser pulses with the eye have been completed and used to establish new national ocular safety standards for laser exposure. The new standards will not only safeguard the warfighter's vision but also help to establish baseline specifications for developing advanced laser-protective eyewear.

3. Biomedical

The fundamental knowledge provided by research in this area will dramatically improve DoD's capabilities to prevent injury and disease, to sustain the health of the force, and to provide efficient and effective combat casualty care when necessary. Advances in immunology, toxicology, physiology, neuroscience, biochemistry, psychology, and molecular biology—all of which are directed toward the understanding of disease and injury processes—will provide the warfighter with new options for increasing survivability and mission effectiveness on modern battlefields. The knowledge will be used to enable applied research for the development of novel drugs, vaccines, medical devices, health promotion and prevention procedures, medical diagnostics, and treatments for trauma and disease. Today military personnel are protected from epidemic hepatitis as a result of knowledge gained from basic research on the biology and immunology of the hepatitis A virus. In addition, basic research into the physiology of thermoregulation has produced mathematical models that are used in the Army Mercury System deployed at Army Ranger training sites to protect trainees from thermal injury (e.g., hypothermia).

Table IV–9 identifies service-specific interests and commonality for this area.

Table IV–9. Service-Specific Interests and Commonality in Biological Sciences

Subarea	Army (A)	Navy (N)	Air Force (AF)
Molecular/Cellular Processes and materials Sensors Biodegradation Chemical and biological defense	Structure, function, and nano-assembly Nanoscale biomechanics Olfactory and integrated multi-functional sensing Sense-and-respond processes Microbial degradation of aromatic compounds	Marine molecular biology Bioadhesion Bioluminescence Fast biosensor arrays Cell-based sensing Computational biology Enzymatic synthesis of energetic materials	Molecular mechanisms of infrared biosensing Novel molecular and computational tools for toxicity prediction
	Areas of Common Interest: biomimetics (A, N, AF); biocatalysis (A, N, AF); chemical and biological defense (A, N)		
Systems/ Organisms Physiology Toxicology	Adaptation and survivability Sustaining and enhancing soldier performance Differentiated bacterial communities Hibernation	Marine mammal physiology Biomimetic sonar Environmental impacts of loud sound Marine environmental microbiology Immunophysiology	Toxic mechanisms of military chemicals Bioeffects of non-ionizing radiation
	Areas of Common Interest: none		
Biomedical Infectious diseases Combat casualty care Military operational medicine Medical chemical-biological defense	Pathobiology of CBW agents Nutrition and thermo-regulation	Physiology and biology of underwater operations	None
	Areas of Common Interest: molecular biology of animals and infectious agents; immunobiology for clinical management; vaccine and drug design; medical physiology, biochemistry, and toxicology; and psychobiology of human health effects (A, N)		

J. COGNITIVE AND NEURAL SCIENCE

The DoD-wide program of research in Cognitive and Neural Science develops the science base enabling the optimization of the services' personnel resources. Areas of application include testing, training, and simulation technologies; display support for target recognition and decision making; techniques to sustain human performance; human factors; and team/organizational design and evaluation methodologies. Joint agreements in 6.2 and 6.3 programs apply to manpower, personnel, and training issues. The defense-wide SPG in Cognitive and Neural Science has been responsive in aligning 6.1 programs in those areas.

DoD basic research activities in Cognitive and Neural Science involve two subareas: human performance and reverse engineering.

1. Human Performance

Research in human performance influences the services' approach to personnel selection, assignment, and training. It also explores ways to augment personnel performance in military environments and to develop new ways of organizing better, more effective teams and command and control organizations.

In research on teams and organizations, the Army concentrates on group-leader processes, the Navy on coordination in distributed groups and models for evaluating organizational design, and the Air Force on communication strategies and interfaces important to maintaining situational awareness. In the areas of cognition, learning, and memory, the Army concentrates on training principles that underlie acquisition, retention, and transfer of soldier skills. The Navy emphasis is on artificial intelligence and AI-based models of cognitive architecture. The Air Force focus is on sensory integration, performance in synthetic task environments for command and control, and information fusion for decision-making support.

In stress and performance research, the Army focuses on performance issues, while the Air Force focuses on the circadian timing system underlying fatigue, performance, and the change from sleep to arousal. The Army vision and audition program seeks to optimize the user interface in visual control of vehicles and reduce the effects of intense sound. Navy research focuses on teleoperated undersea requirements, automatic target recognition for precision strike missions, and auditory pattern recognition for sonar signal analysis. More generic principles of human image communication and sound localization are being investigated by the Air Force.

2. Reverse Engineering

The reverse engineering subarea exploits the unique designs of biological neural systems by discovering novel information processing architectures and algorithms potentially implementable in engineered systems. These efforts seek to imbue machine systems with capabilities for sensing, pattern recognition, learning, locomotion, manual dexterity, and adaptive control that approximate human functionality. The current Navy program in reverse engineering combines neurosciences and computational modeling in five topical areas: vision, touch/manipulation, locomotion, acoustics/biosonar, and learning. The Air Force examines biological sensor system specificity and sensitivity to provide, for example, new technologies for ambient-temperature, lightweight, low-cost infrared sensors by examining the mechanisms used by animals to detect IR signals.

Table IV–10 provides an outline of service-specific interests and commonality in this area.

Table IV–10. Service-Specific Interests and Commonality in Cognitive and Neural Science

<table>
<tr><th>Subarea</th><th>Army (A)</th><th>Navy (N)</th><th>Air Force (A)</th></tr>
<tr><td rowspan="2">Human Performance
Personnel selection
Training
Human-system integration
Teams and organizations</td><td>Leadership
Societal linkages</td><td>Tactile information processing
Sensory-guided motor control</td><td>Chronobiology
Neuropharmacology
Synthetic task environments</td></tr>
<tr><td colspan="3">Areas of Common Interest: teams and organizations (A, N, AF); cognition, learning, and memory (A, N, AF); stress and performance (A, AF); auditory and visual perception (A, N, AF)</td></tr>
<tr><td rowspan="2">Reverse Engineering
Machine vision
Autonomous vehicles
Automatic target recognition
Telerobotics</td><td rowspan="2">None</td><td>Autonomous undersea vehicle/manipulators
Neural computation plasticity
Automatic sonar classification</td><td>3D audio displays
Infrared biosensors</td></tr>
<tr><td colspan="2">Areas of Common Interest: machine vision (N, AF)</td></tr>
</table>

K. DISTRIBUTION OF FUNDING AMONG THE RESEARCH AREAS

The distribution of funding among the 12 disciplinary research areas as a percentage of the total available dollars is shown in Figure IV-1. This pie chart is based on estimates and should not be confused with firm budget numbers, which are not broken down by discipline.

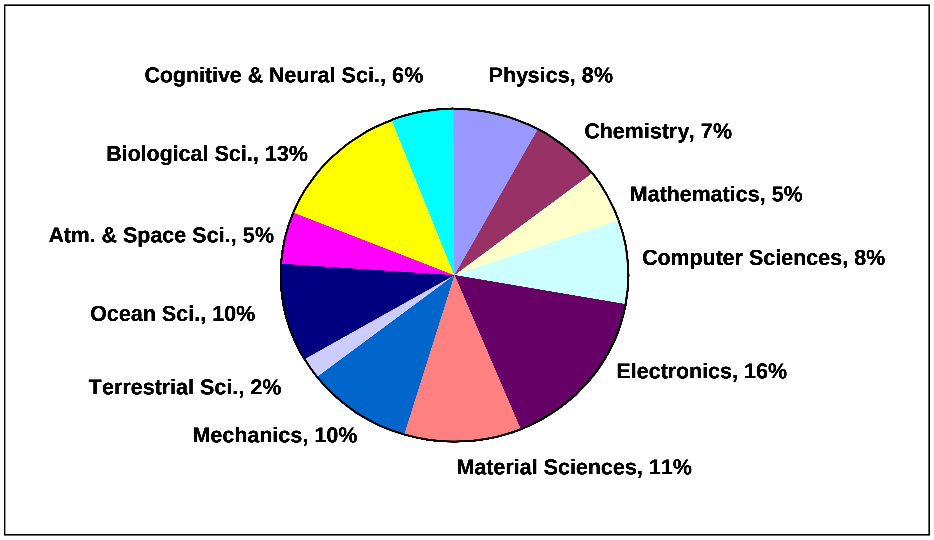


Figure IV–1. Total Basic Research Funding Distribution by Research Area

CHAPTER V
MULTIDISCIPLINARY UNIVERSITY RESEARCH INITIATIVE

The Multidisciplinary University Research Initiative (MURI) Program is the principal element of the DoD University Research Initiative (URI). The URI is a DoD initiative sponsored by the Office of the Director of Basic Research, Office of the Deputy Under Secretary of Defense for Science and Technology (OUSD(S&T)), to enhance universities' capabilities to perform basic science and engineering research and related education in areas related to national defense.

The Multidisciplinary University Research Initiative program supports university teams whose research efforts interact with more than one traditional science and engineering discipline. Multidisciplinary teams under one project leader promote cross-fertilization of ideas and direct their efforts toward a common practical goal. In addition, these teams accelerate the transition from research to application. In this process, these teams also help train graduate students in science and engineering fields appropriate to DoD needs. The MURI team efforts complement other DoD programs that support university research, principally through single investigator awards.

Typically, the MURI awards are for a basic period of 3 years with 2 additional years possible as options to bring the total award to 5 years. The award generally ranges from $500,000 to $1,000,000 per year. The FY99 MURI competition resulted in 19 awards for 13 topics. By contrast, single-investigator awards typically amount to about $100,000 per year, and may be limited to 1 year. With award levels to MURI teams so much higher, MURIs are in a position to provide significantly more funding for critical university research infrastructure than can traditional, single-investigator projects. This funding includes training for more graduate students and acquiring or modernizing equipment needed to conduct the proposed research—equipment that is usually expensive and that would be inappropriate to provide to a single investigator.

A key element of the MURI program is the support of graduate students designated as MURI Fellows. The MURI fellowship recognizes excellence in research and increases the number of U.S. graduate students in multidisciplinary research. Each university team can request and propose support for MURI Fellows. If the proposal is successful, DoD provides support, for 3 years, for up to a maximum of three MURI fellows per MURI award.

The DoD encourages proposals from university consortia because research in multidisciplinary topics requires teams with strengths in a multitude of science and engineering fields, which may not reside at a single university. Given the relatively large size of MURI awards, fusion of ideas can be achieved more readily when investigators with different backgrounds collaborate toward a common objective, than when they work independently of one another. Relevance and potential contributions to the defense mission as well as the quality of the research are primary considerations. Interaction with industry is encouraged with a view to earlier transitions.

The URI was initiated in 1983 to fund interdisciplinary teams at universities. As the program took off, it was expanded to include multi-university teams as well, and to encourage industry interactions where appropriate (but without DoD funding to the industry participants). These larger grants also made it possible for the universities to acquire and share more modern and expensive instrumentation than would have been possible through single-investigator grants. Other innovations included special fellowships for gifted students working on the research team. The major research grants within the multifaceted URI program came to be known as MURIs (Multidisciplinary URI (grants)). Between FY94 and FY00, 145 MURI projects were initiated. Most of the FY00 MURI awards were associated with advancing the state of the art in information technology. That year, awards were made in the following 13 topic areas (only university team leaders are shown in the parentheses, but many more universities participated):

- Data Fusion in Large Array of Microsensors (MIT)
- Mobile Augmented Battlespace Visualization (UC Berkeley)
- Solitonic Information Processing (U. Central Florida)
- Quantum Communication and Quantum Memory (Caltech, MIT)
- Ultracold Atom Optics (Yale, U. Colorado)
- Decision Making Under Uncertainty (UCLA, UC Berkeley)
- Tutorial Dialog of Artificial Intelligence Training Systems (U. Pittsburgh, Stanford)
- Adaptive Mobile Wireless Networks (Cornell, Clemson)
- Science Underpinning Prime Reliant Coatings (Princeton)
- Fundamental Principles in Adaptive Learning (Texas A&M)
- Real-Time Fault-Tolerant Network Protocols (UC Berkeley, UC Santa Barbara)
- Phonon-Enhancement of Electronic and Optoelectronic Devices (U. Michigan, Brown)
- Programmed Surface Chemical Assembly of Functional Materials (Northwestern).

Each research team involved numerous universities that contributed to the research efforts. In addition to these programs initiated in FY00, more than 100 university teams continued to be involved in programs that were continued from previous years. This listing provides an illustration of the breadth of the MURI program and the multi-university nature of the program.

The FY01 MURI program awards are expected to be announced by May 1, 2001, and will involve 38 research topics focused in the following areas: biomimetics, cognitive readiness, compact power, electronics, information technology, nanoscience, nanotechnology, smart materials and structures, and smart sensor webs. These topic areas closely match the Strategic Research Areas listed in Chapter VI.

In FY02, the MURI programs will focus on four broad research themes:

Energetics—deals with the scientific understanding of energy and its transformations to include production, storage, release, and conversion from one form to another. Multidisciplinary approaches involving chemistry, physics, biology, mathematics, and engineering sciences will be emphasized. Potential high-payoff contributions to a wide array of DoD needs in explosives, propulsion, power, warrior readiness, and others are expected as a result of this research.

Multifunction Materials—deals with the scientific understanding needed to develop materials able to perform more than one function, such as sensing, electrical or optical conduction, flexible (adaptive) response to stimuli, structural integrity, durability, biodegradability, and manufacturability. Multidisciplinary approaches involving mathematics, chemistry, biology, physics, and engineering sciences will be emphasized. Potential high-payoff contributions to a large number of DoD needs related to adaptive response to changing environments, propulsion, sensors, munitions, warrior readiness, weapons platforms, autonomous systems, information flow, and others are expected to result from this research.

Synergistic Sensing—deals with the scientific understanding needed to develop a variety of new sensors and techniques for fusing sensor signals to provide a synergistic “picture" of the operational environment. Multidisciplinary approaches involving physics, chemistry, biology, mathematics, computer and information sciences, and engineering sciences will be emphasized. Potential high-payoff contributions to DoD needs in battlefield awareness, combating terrorism, chemical/biological defense, warrior readiness, information flow, decision making, autonomous systems, and others are expected to result from this research.

Control for Adaptive and Cooperative Systems—deals with the fundamental principles needed to develop new methodologies required for high-precision navigation and precision timing and control of highly dynamic groups of both human-operated and autonomous vehicles and robots. Multidisciplinary approaches involving mathematics, physics, computer and information sciences, and engineering sciences will be emphasized. Potential high-payoff contributions to DoD needs related to adaptive command and control of swarms of uninhabited vehicles, robots, and satellite clusters will be achieved from research in this theme.

CHAPTER VI
STRATEGIC RESEARCH AREAS

The Basic Research Program of the Department of Defense supports a broad range of activities spanning many scientific disciplines. The results of these extensive fundamental research efforts provide a sound technical foundation for meeting both the recognized current U.S. defense requirements as well as projected but less well defined future needs. To focus attention on a few of the most exciting research areas that offer significant and comprehensive benefits to our national peacekeeping and warfighting capabilities, the following six Strategic Research Objectives (SROs) were established in 1995 (these SROs are being reviewed and strengthened as Strategic Research Areas (SRAs) for 2001).

- *Biomimetics*—research to develop novel synthetic materials, processes, and sensors through advanced understanding and exploitation of design principles found in nature.
- *Nanoscience*—research to achieve dramatic and innovative enhancements in the properties and performance of structures, materials, and devices that have controllable features on the nanometer scale (i.e., tens of angstroms).
- *Smart Materials and Structures*—research to demonstrate advanced capabilities for modeling, predicting, controlling, and optimizing the dynamic response of complex, multielement, deformable structures used in land, sea, and aerospace vehicles and systems.
- *Information Technology (IT)*—research to provide fundamental advances enabling the rapid and secure transmission of large quantities of multimedia information (speech, data, images, and video) from point to point, broadcast, and multicast over distributed networks of heterogeneous communications, command, control, computers, intelligence, surveillance, and reconnaissance (C^4ISR) systems.
- *Human-Centered Systems*—research to develop advanced systems that can sense, analyze, learn, adapt, and function effectively in uncertain, changing, and hostile environments in achieving the mission.
- *Compact Power*—research to exploit new concepts to achieve significant improvements in the performance of compact power sources and power consuming devices through fundamental advances relevant to current technologies.

These SRAs were selected on the basis that (1) they support DoD missions, (2) they have the potential to result in significantly enhanced capabilities for the peacekeepers and warfighters, (3) they are highly visible and broad areas of substantial DoD investment, (4) they are cross-disciplinary and multidisciplinary in nature, (5) they require sustained investment over a long period of time, and (6) they have the potential for major scientific breakthroughs. The SRAs cut across the Reliance Basic Research Areas to provide focus on areas in which interdisciplinary work should have major payoffs for DoD.

The SPGs and the SRA coordinating committees provide coordinated tri-service oversight for research in these areas. Research activities in the technical disciplines tend to concentrate on the scientific disciplines involved, whereas the SRAs tend to focus on interdisciplinary approaches to enhance DoD capabilities. The SRAs tend to be multidisciplinary, as shown in Table VI–1.

Table VI–1. Correlation Between SPG Disciplines and Strategic Research Areas

Scientific Disciplines	Strategic Research Areas					
	Biomimetics	Nano-Science	Smart Materials and Structures	Information Technology	Human-Centered Systems	Compact Power
Physics		X	X			X
Chemistry	X	X				X
Mathematics				X	X	
Computer Sciences	X	X		X	X	
Electronics	X	X	X	X	X	X
Materials Science	X	X	X			X
Mechanics			X		X	
Terrestrial Sciences				X		
Ocean Sciences				X		
Atmospheric and Space Sciences				X		
Biological Sciences	X	X	X		X	
Cognitive and Neural Science	X				X	

These six strategic research areas reflect the high-payoff potential of multidisciplinary research areas among the broadbased research in various scientific disciplines and reflect the continuing importance of these areas to achieving critical new capabilities for many types of military missions. These Strategic Research Areas—and their associated research thrusts—are as follows.

A. BIOMIMETICS

1. Objective

Enable the development of novel synthetic materials, processes, sensors and systems through advanced understanding and exploitation of design principles found in nature.

2. Thrusts

- Biosensors
- Biomaterials
- Bioprocesses.

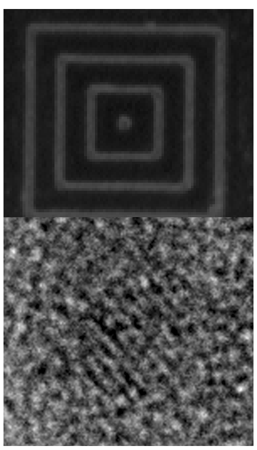
3. DoD Applications

- Intelligent automatic target recognition

- Chemical/biological warfare defense
- Agility and control in stressful environments
- High-strength and flexible-armor materials.

Materials and structures of intricate complexity and exhibiting remarkable properties are found throughout the biological world. A unique feature of many biological systems is that their functionality derives from fabrication processes composed of several levels of self-assembly involving molecular clusters organized into structures of different length scales. The resulting structure is an optimized architecture tailored for specific applications through molecular, nanoscale, microscale, and macroscale levels that is unobtainable through conventional, equilibrium-based, synthetic fabrication methods.

The integration of the principles of biotechnology with materials science and engineering to create a new field called biomimetics establishes a conceptual approach for unraveling many of nature's secrets. Biological system characteristics of interest include infrared signature visualization, exquisite sensing capabilities like sniffing and tasting that allow rapid and selective detection of only a few molecules of certain chemical species for biochemical defense, echolocation that can detect and classify objects in noisy and cluttered environments, heightened agility and control capabilities in stressing environments, and protection of animals by shells and horns. Examples of possible products of biomimetics research include adhesives for emergency repairs and composite lightweight armor materials that integrate very hard and softer components to optimize strength and toughness. Advances in the field of biomimetics are also likely to contribute to accelerated production of designer vaccines and pharmaceuticals, novel gene therapies, and new detectors for environmental monitoring.



Professor Angela Belcher and her colleagues at University of Texas have identified peptides that select for and specifically bind to inorganic semiconductor nanoparticles or nanoparticles of iron and tin oxides. The goal is to be able to spatially and temporally nucleate inorganic structures via selectivity and recognition to control size, distribution, and assembly for the patterning and interconnection of electronic and magnetic materials on nanometer-length scales. Shown in the top part of the figure is recognition of III–V semiconductor materials by one member clone of a phage display library, a combinatorial library of biologically evolved random peptides, where that one peptide is able to select and specifically bind electronic materials. The fluorescently labeled phage clone is bound to GaAs (concentric orange pattern), but not to the surrounding SiO_2. Shown in the bottom part of the figure is the lattice image of a ZnS.

Figure VI–1. Biomolecular Recognition of Semiconductors and Magnetic Materials to Pattern Quantum-Confined and Magnetoelectronic Structures

4. Funding

Funding for Biomimetics is presented in Section G.

B. NANOSCIENCE

1. Objective

Achieve dramatic, innovative enhancements in the properties and performance of structures, materials, and devices that have controllable features on the nanometer scale (i.e., tens of angstroms).

2. Thrusts

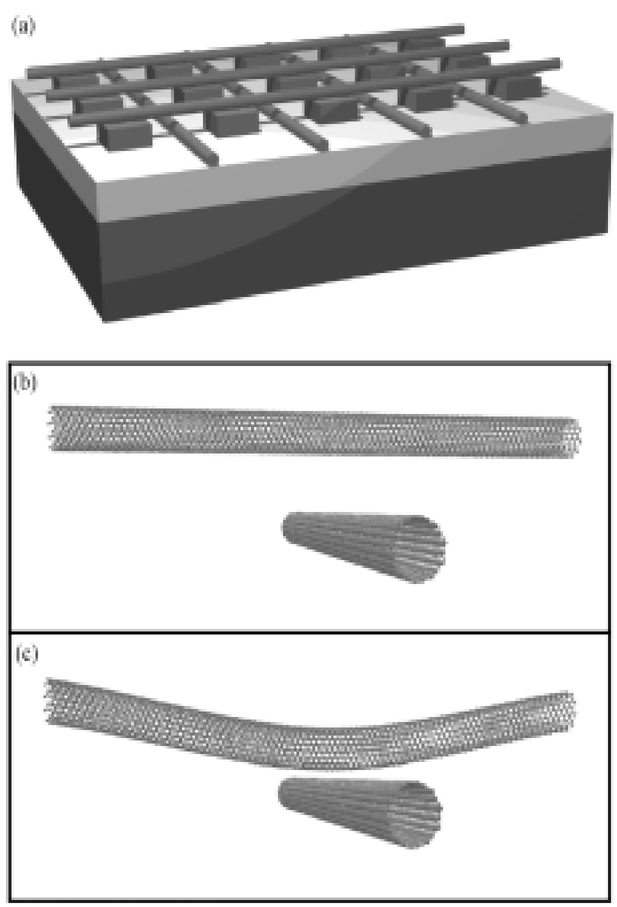
- Fabrication, synthesis, and processing of nanostructures
- Nanoscale characterization
- Novel phenomena and properties
- Nanodevice concepts.

3. DoD Applications

- High-density information storage (terabits)
- Superfast computers
- Image and information processors
- Low-power personal communication devices
- Miniaturized sensor suits for surveillance
- Warfighter personal status monitors, especially chemical/biological
- High-performance, affordable nanocomposite structures
- Miniaturized robotics and uninhabited platforms, especially for Military Operations on Urbanized Terrain (MOUT).

The ability to affordably fabricate structures at the nanometer scale will enable new approaches and processes for manufacturing novel, more reliable, lower cost, higher performance, and more flexible electronic, magnetic, optical, and mechanical devices. Recognized applications of nanoscience include ultrasmall, highly parallel and fast computers with terabit nonvolatile random-access memory and teraflop speed; image information processors; low-power personal communication devices; lasers and detectors for weapons and countermeasures; optical (infrared, visible, ultraviolet) sensors for improved surveillance and targeting; integrated sensor suites including chemical and biological agent detection; catalysts for enhancing and controlling energetic reactions; synthesis of new compounds (e.g., narrow-bandgap materials and nonlinear optical materials) for advanced electronic, magnetic, and optical sensors; and significant life-cycle cost reductions in many systems through failure prevention. These various applications will exploit exciting properties of nanoscale materials not predictable from macroscopic physical and chemical principles.

DoD support for nanoscience research is focused on creating new theoretical and experimental results involving atomic-scale imaging methods, sub-angstrom measurement techniques, and fabrication methods with atomic control that will provide reproducible material structures and novel devices. It also includes investigations of phenomena dominated by size effects or quantum effects. Since the traditional disciplines of physics, chemistry, biology, and materials are essentially indistinguishable at the nanoscale, interdisciplinary efforts are strongly emphasized. Scientific opportunities include understanding new phenomena in low-dimensional structures, nucleation and growth, self-organizing materials, site-specific reactions, elastic/plastic deformation, nanostructural materials, solid-fluid interfaces, and supramolecular materials. This SRA will directly contribute to the goals in the Biomimetics, Smart Materials and Structures, and Compact Power strategic research areas.



(a) Schematic illustrating a periodic suspended nanotube crossbar array with a device element at each crossing point. The substrate consists of a conductor (e.g., highly doped silicon, dark-grey) that terminates in a thin dielectric layer (e.g., SiO2, light gray). The lower nanotubes (dark gray cylinders) are supported directly on the dielectric film, while the upper nanotubes are suspended by patterned inorganic or organic supports (dark gray blocks).

The device elements at each crossing have two stable states: *off* and *on.* The *off* state (b) corresponds to the case where the nanotubes are separated, while the *on* state (c) is when the tubes are in van der Waals contact. A device element is switched between *off* and *on* states by applying voltage pulses that transiently charge the nanotubes to produce attractive or repulsive forces.

After switching, the junction resistance can be read by measuring the current through the junction at a bias voltage much smaller than the voltage necessary for switching. (b) and (c) correspond to the calculated shapes of *off* and *on* states for a 20 nm (10,10) Single Walled Nanotube, where the initial separation is 2.0 nm.

Source: Lieber, Harvard U.

Figure VI–2. Suspended Nanotube Device Architecture

Recognized applications of nanoscience include ultrasmall, highly parallel, and fast computers with terabit nonvolatile random access memory and teraflop speed; image information processors; low-power personal communication devices; high-density information storage devices; lasers and detectors for weapons and countermeasures; optical (infrared, visible, ultraviolet) sensors for improved surveillance and targeting; integrated sensor suites for chemical and biological agent detection; catalysts for enhancing and controlling energetic reactions; synthesis of new compounds (e.g., narrow-bandgap materials and nonlinear optical materials) for advanced electronic, magnetic, and optical sensors; and significant life-cycle cost reductions in many systems through failure remediation. These devices exploit exciting properties of nanoscale materials not predictable from macroscopic physical and chemical principles.

The hybrid structure seen at the right contains a 1D chain of endohedral fullerenes. The diameter of the C_{80} cage (0.8 nm) requires a reduced Van der Waals gap between the fullerene and the singe-walled nanotube (SWNT) compared to C_{60}@SWNT. This structure is consistent with $(La^{3+})_2C_{80}^{6-}$ electronic structure. The measured maximum La–La separation (0.39 nm) exceeds theoretical calculations by 0.03 nm, suggesting a strong endohedral–SWNT interaction.

Source: Luzzi, et al., U. Penn

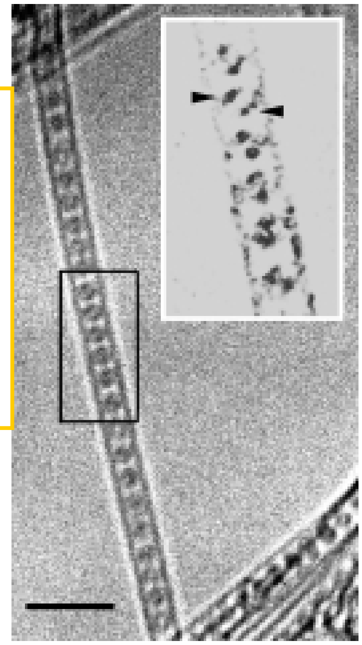


Figure VI–3. 1–D Chain of Endohedral Fullerenes

DoD support for nanoscience research is focused on creating new theoretical and experimental results involving atomic-scale imaging methods, sub-angstrom measurement techniques, and fabrication methods with atomic control that will provide reproducible material structures and novel devices. Support also includes investigations of phenomena dominated by size effects or quantum effects. Scientific opportunities include understanding new phenomena in low-dimensional structures, nucleation and growth, self-organizing materials, site-specific reactions, elastic/plastic deformation, nanostructural materials, solid-fluid interfaces, and supramolecular materials.

4. Funding

Funding for Nanoscience is presented in Section G.

C. SMART MATERIALS AND STRUCTURES

1. Objective

Demonstrate advanced active materials that can adapt in real or near-real time to the changing environment in response to electric, magnetic, mechanical, thermal, and chemical stimuli and capabilities for modeling, predicting, controlling, and optimizing the dynamic response of complex, multielement, adaptive deformable structures used in land, sea, and aerospace vehicles and systems.

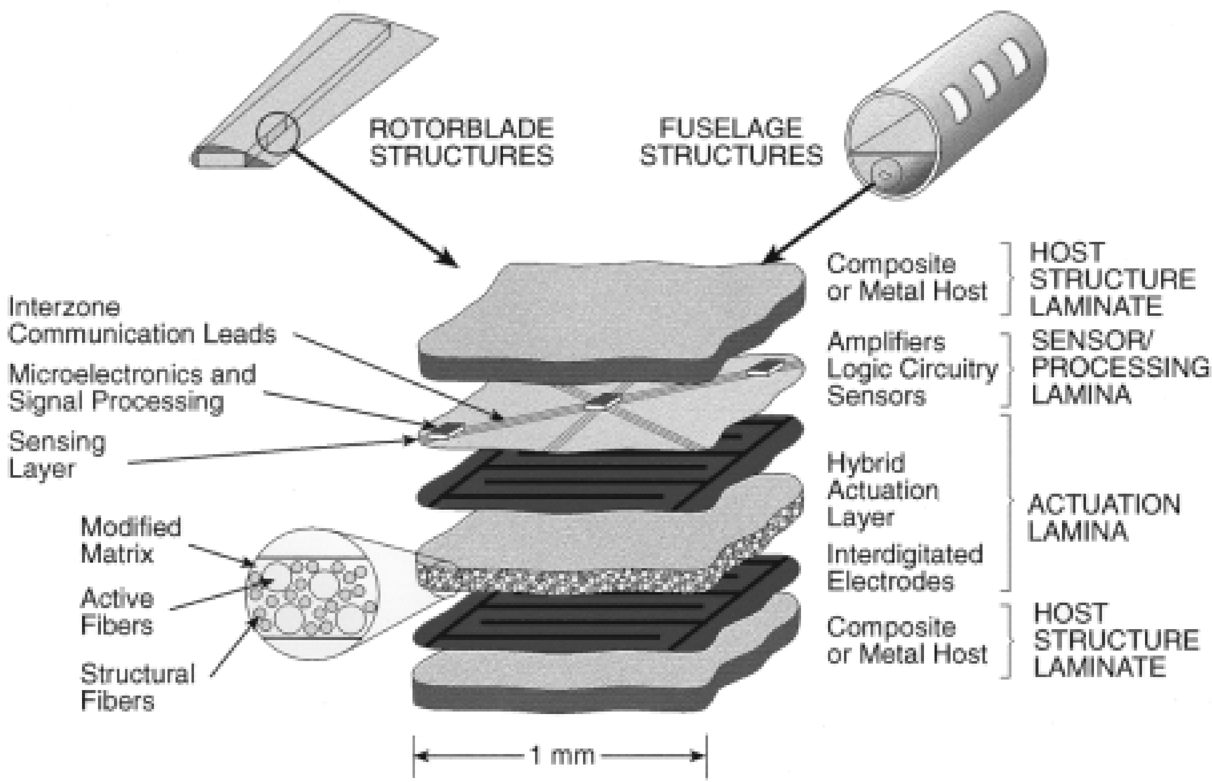
2. Thrusts

- High-performance active materials (piezoceramics, relaxor ferroelectrics, shape memory alloys, etc.)
- Adaptive and reconfigurable structures with distributed sensors and actuators
- Multiscale computational design of structural materials with embedded functionality
- Materials with embedded electrical/magnetic/optical functionality
- Self-assessing and damage-mitigating materials
- Dynamic-resistance smart materials.

3. DoD Applications

- Platform protection and resistance and vibration noise control in submarines and torpedoes
- Shape and flow control to reduce cavitation under water or dynamic stall in aerodynamics
- Stability augmentation systems for fixed-wing and rotary-wing aircraft
- Vibration suppression in weapon systems to improve pointing and tracking accuracy
- Conformal, load-bearing antenna structures and phased arrays
- Gross shape control of self-deploying space mirrors and antennas
- Smart skins for stealth applications in high-performance combat aircraft
- Defense infrastructure protection and threat reduction.

Smart materials and structures offer significant potential for expanding the effective operations envelope and improving certain critical operational characteristics for many DoD systems. To realize the full potential of smart materials and structures in military systems, DoD supports fundamental investigations that address active/passive structural damping techniques, advanced actuator concepts able to provide greater forces and displacements, embeddable and nonintrusive sensors, and smart actuator materials (e.g., piezoelectric and electrorestrictive materials, ferromagnetic and other shape memory alloys, magnetorheological fluids). Research is focused on new material design and fabrication processes for actuators and sensors on the micron to millimeter scale, computationally accurate and efficient constitutive models for smart materials, advanced mathematical models for nonconservative and nonlinear structural and actuator response, robust hierarchical control with distributed sensors and actuators, structural health monitoring techniques, agile signature control to avoid detection, and concurrent, integrated structural design and control methodologies.



These elements could be used to twist a helicopter rotor blade, silence torpedoes, and reduce acoustic effects in sea launch vehicles.

Figure VI–4. Elements of an Active-Fiber Composite Actuator With Piezoelectric Fibers and Interdigital Electrodes

Specific potential military applications of smart structures include platform protection and resistance and machinery vibration and radiated noise control in submarines and surface ships; noise suppression and shape and flow control in submarine propulsors to reduce signature, improve maneuvering control, and eliminate cavitation; vibration control and stability-augmentation systems in fixed- and rotary-wing aircraft; vibration control and precision metrology of surveillance spacecraft systems; barrier structures providing improved protection against chemical and biological agents; structural damage detection and mitigation systems; more accurate rapid-fire weapon systems; fire-control and battle-damage identification, assessment, and control on surface ships; control of conformal electromagnetic antennas, phased arrays, and broadband spiral antenna systems; and smart skins for high-performance stealthy combat aircraft.

The development of an active-fiber composite actuator concept in a MURI program at MIT led to reduced vibration amplitudes and blade-vortex interaction noise produced by a twistable helicopter rotor blade and to diminished vibration levels in torpedo hulls and sea launch vehicles. First-principle-based calculations of piezoelectric response functions have led to the successful prediction of the dielectric constant and piezoelectric constants of materials, rendering possible the capability to design new smart ferroelectric materials. Analogous analyses and computations for magnetostrictive materials (iron, cobalt, and nickel) yielded good agreement with experimental data. This opens the path to designing active materials with significantly improved actuation output potential. In addition, researchers have discovered two techniques of producing high-quality single piezocrystals of the promising active material consisting of lead-zirconate-niobate with lead-titanate. This yields materials with greatly improved coupling coefficients, which deliver greater actuation stroke and force levels. These materials have been transitioned to DARPA for application in sonar and actuators. Electrochromic polymers along with an electrolyte—a set of patterned electrodes layered on a flexible substrate—have been assembled in a thin skin. This combination produces a color pattern on the flexible substrate in which controllable color changes can be realized. Such a smart skin makes possible infrared signature control in combat aircraft.

4. Funding

Funding for Smart Materials and Structures is presented in Section G.

D. INFORMATION TECHNOLOGY

1. Objective

Provide fundamental advances enabling the collection, storage, processing, communication, networking, dissemination, retrieval, and display of large quantities of multimedia information (speech, data, graphics, and video).

2. Thrusts

- Mobile wireless and undersea communications
- Robust and responsive networks
- High-assurance information and communication systems
- Verifiably correct and reliable complex software
- Sensor information processing and networks
- Information integration and fusion
- Revolutionary computing, display, and interaction paradigms
- Foundations of modeling and simulation.

3. DoD Applications

- Command, control, communications, computers, intelligence, surveillance, and reconnaissance (C^4ISR)
- Network-centric warfare
- Information dominance
- Common and complete tactical picture
- Augmented battlespace visualization
- Robust and secured mobile communications.

Research in information technology provides the foundation for orders-of-magnitude increases in information processing capabilities by digital computers. Areas of research include software engineering to enable increased software productivity and reliability; high-confidence computing systems with assured composed behavior and information security; networks that provide reliable, secured, and robust quality of service (QoS); human-centered computing systems that can serve as knowledge repositories for information access, management, and application; and high-end computing that will lead to future generation of computers that are orders of magnitude faster than today's fastest supercomputers. Such high-end computing research will lead to advanced technologies and innovative computing architectures.

Figure VI–5. Augmented Visualization at Columbia University

4. Funding

Funding for Information Technology is presented in Section G.

E. HUMAN-CENTERED SYSTEMS

1. Objective

Provide theory and models of expert performance to enable technologies that maintain, augment, or reliably duplicate operator control of complex weapons systems.

2. Thrusts

- Cognitive performance modeling
- Human–system interface
- Physiology of stress
- Distributed/collaborative decision making
- Intelligent training.

3. DoD Applications

- Robust command and control for future battlefields
- Multi-echelon common operating picture
- Increased unit readiness

- Enhanced technical training technologies
- Simulated forces for training, modeling, and simulation
- Semiautonomous and automated decision systems.

Future military systems are expected to require many fewer yet more capable decision makers working in geographically distributed flexible groups, informed by a common operating picture, to supervise semiautomated systems. This future goal is motivated largely by desires to reduce the considerable cost of maintaining a large pool of experts (technical training alone costs the DoD tens of billions of dollars annually) while increasing the speed, accuracy, and survivability of force deployments. Multiple technologies will contribute to achieving this goal, but those impacting human situational awareness will critically benefit from a fundamental understanding of human capabilities. This strategic research area enables technology innovations to maintain and enhance the cognitive readiness of military forces.

Thrusts in this strategic research area contribute to primary aspects of human-centered systems. For example, fundamental work on modeling the decision making of experts provides a basis for design of training systems, for technologies of decision aiding and intelligent agents, and for benchmarking expert performance essential to determining the impact of innovations across the design space of human-centric systems. Work on advanced concepts for human system interfaces, which includes research on sensory and motor systems, contributes to high-bandwidth, error-free control by human operators that is robust to increasing workload demands or dynamic reallocation of function between human and machine. Research on stress physiology, including new tools for objective measurement of workload, contributes to discovery of stress mitigation technologies—perhaps pharmaceutical in nature or provided through adaptive interface designs. Research on collaborative and distributed decision making, which includes measuring the impact of social variables and leadership, provides a basis for scalable command architectures that dynamically adapt to changing workload or functional requirements. Lastly, research on intelligent training contributes to technologies for continuous training embedded in operational equipment, to adaptive interfaces through individualized coaching systems, and to the design and calibration of realistic synthetic forces used in large training scenarios and in modeling and simulation of command structures.

Multiple scientific disciplines contribute to progress in each thrust, from neuroscience and brain imaging in studies of perceptual-motor systems and stress physiology, through psychological cognitive task analysis in synthetic task environments for study of benchmark performance levels, to computer science and engineering approaches to modeling adaptive decision rules for intelligent tutoring systems and software agents for job aiding. As a result, work in Human-Centered Systems couples closely with that in Information Technology, concerning network-centric warfare and information dominance; and in Biomimetics, concerning intelligent automatic target recognition.

4. Funding

Funding for Human-Centered Systems is presented in Section G.

F. COMPACT POWER

1. Objective

Achieve significant improvements in the performance (power and energy density, stealth, reliability, and safety) of portable energy systems under all military operational conditions through fundamental advances in the science of energy conversion and management.

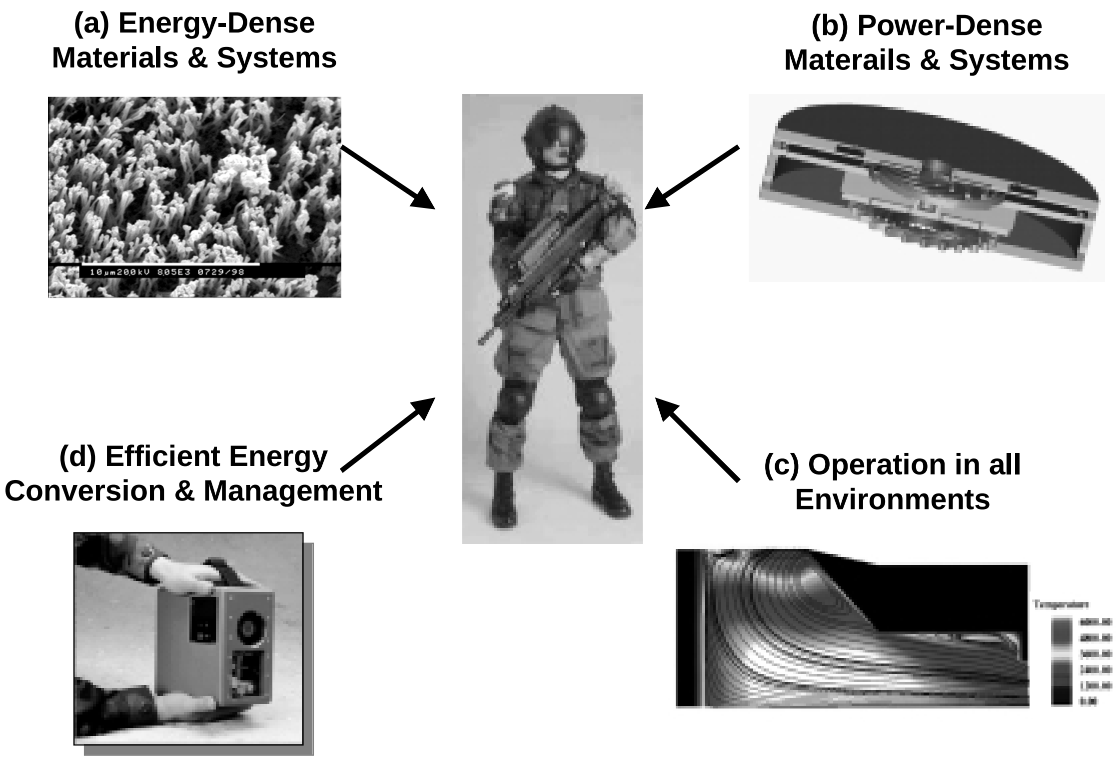
2. Thrusts

- Energy-dense materials and systems
- Power-dense materials and systems
- Efficient energy conversion and management
- Environmentally constrained systems
- Compact power sources.

3. DoD Applications

- Portable computing, communication, and climate control systems
- High-performance micro- and mesoscale autonomous vehicles and microsatellites
- Smart weapons
- Lightweight night vision equipment
- Remote environmental sensing and monitoring systems
- Low-power surveillance devices.

The individual soldier and marine relies heavily on electrical energy to operate the array of electronics, weaponry, and protective gear required for today's networked warfighting and peacekeeping missions. Although advanced electronics operate at lower power levels, these reductions in energy requirements are offset by increasing mission times, the need to minimize in-field logistics support for expeditionary forces, and the need to reduce power source weight to accommodate additional gear. Therefore, S&T investments in compact power are needed to increase the warfighter mobility and endurance with technologies that provide the stealth, reliability, affordability, and broad power ranges required for military operations. The same S&T investments in compact power for the individual warfighter are also key enablers for full-capability autonomous vehicles and for affordable, reliable satellites. Besides requiring specific performance parameters, many power source applications also require high performance in constrained environments (e.g., undersea and space) and under adverse battlefield conditions.



Combining advanced energy and power-dense materials with efficient energy conversion and management designs will provide high-performance, compact power sources to the warfighter: (a) nanoscale tubular cathode material for high-energy-density rechargeable battery; (b) MEMS-based micro-turbine for high-power-density portable power system; (c) modeling of hydroreactive thermal energy conversion engine for underwater power source; and (d) Integrated fuel cell system for portable power.

Figure VI–6. Compact Power Sources for the Warfighter

To meet the extreme power demands for the future warfighter, fundamental research is needed to discover and develop new high-performance energetic materials, efficient chemical and energy conversion processes, and complex systems integration strategies. These advancements can only be achieved through a multidisciplinary effort that creates new research directions and leverages S&T opportunities in a range of exciting research frontiers, including nanoscience, micro-electromechanical systems (MEMS), micro-chemical systems, bio-energetics, and physics-based modeling. Besides meeting military power requirements, DoD research also must be mindful of future worldwide energy needs and research directions to realize a sustainable and affordable military power sources infrastructure. Therefore, fundamental research opportunities in fuel cells, micro-turbines, energy harvesting technologies, renewable fuels, and hybrid power systems must be explored for their applicability to military systems.

4. Funding

Funding for Compact Power is presented in Section G.

G. SUMMARY AND FUNDING

The DoD Basic Research Program builds the technological foundation for future warfighting and peacekeeping capabilities, and the long-range research supported in the Strategic Research Areas will lead to defense capabilities in various military systems and operations. These SRAs support the capability requirements described in various DoD planning documents such as *Joint Vision 2020* (Ref. 3). Consideration of many projected research results for these areas relative to numerous specific technology objectives cited in the *Defense Technology Area Plan* (Ref. 10) has served to underscore the pervasive importance of the Strategic Research Areas to improving U.S. defense capabilities applicable to a wide range of military systems and operations. In managing the Basic Research Program, special attention is being given to these areas to help ensure that their great potential can be realized through subsequent technology and system development efforts. Identification of additional such areas will be sought in continuing reviews of basic research activities. Funding data for basic research work supporting the Strategic Research Areas is provided in Table VI–2.

Table VI–2. Funding Profiles for Basic Research Supporting Strategic Research Areas ($ millions)

Strategic Research Areas	FY99		FY00		FY01	
Biomimetics	Army	1.6	Army	2.3	Army	1.3
	Navy	10.6	Navy	11.0	Navy	7.3
	Air Force	0.9	Air Force	1.1	Air Force	1.2
	OSD	17.0	OSD	15.3	OSD	9.3
	Total	30.1	Total	29.7	Total	19.1
Nanoscience	Army	7.0	Army	7.0	Army	12.0
	Navy	15.0	Navy	20.0	Navy	30.0
	Air Force	2.0	Air Force	5.0	Air Force	5.0
	DARPA	34.0	DARPA	40.0	DARPA	50.0
	OSD	13.0	OSD	16.0	OSD	36.0
	Total	71.0	Total	$88.0	Total	$133.0
Smart Materials and Structures	Army	0.5	Army	0.5	Army	0.4
	Navy	4.1	Navy	4.3	Navy	4.4
	Air Force	1.8	Air Force	1.9	Air Force	1.9
	OSD	5.6	OSD	4.0	OSD	4.8
	Total	12.0	Total	10.7	Total	11.5
Information Technology	Army	26.0	Army	32.0	Army	33.0
	Navy	19.0	Navy	20.5	Navy	21.0
	Air Force	9.0	Air Force	8.6	Air Force	9.0
	DARPA	10.0	DARPA	10.0	DARPA	10.0
	OSD	36.0	OSD	44.0	OSD	45.0
	Total	100.0	Total	115.1	Total	118.0
Human-Centered Systems	Army	4.2	Army	5.5	Army	6.2
	Navy	21.3	Navy	16.2	Navy	11.6
	Air Force	12.2	Air Force	12.8	Air Force	13.5
	Total	37.7	Total	34.5	Total	31.3
Compact Power	Army	3.0	Army	2.5	Army	3.0
	Navy	3.1	Navy	4.1	Navy	4.2
	Air Force	0.6	Air Force	0.7	Air Force	0.7
	DARPA	9.4	DARPA	5.0	DARPA	0.0
	OSD	4.7	OSD	3.6	OSD	3.9
	Total	20.8	Total	15.9	Total	11.8
GRAND TOTAL SRA		271.6		293.9		324.7

CHAPTER VII
DEFENSE BASIC RESEARCH FUNDING

A. FY01 FUNDING CONTEXT AND COMPARISON

1. DoD and Federal Basic Research Funding Compared

To place the funding of the DoD Basic Research Programs in the proper context, it is useful to compare the funding levels of DoD basic research with those of other federal agencies. The basic research funding distribution among federal agencies for FY00 (data from Ref. 11) is shown in Figure VII–1. The chart shows that the National Institutes of Health (NIH) received $9.6 billion or 50 percent of the total of federally funded basic research of $19.1 billion. NASA and NSF garnered approximately $2.5 billion or 13 percent each, while the Department of Energy received $2.3 billion or 12 percent of the total. The Department of Defense received approximately $1.2 billion, or 6 percent of the total federally funded basic research.

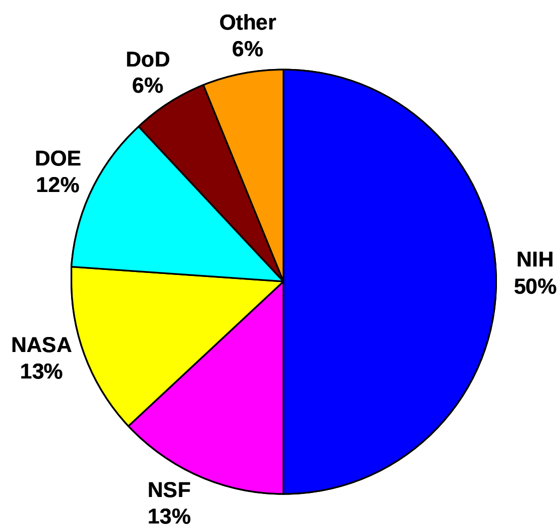


Figure VII–1. Basic Research Funding Distribution Among Federal Agencies, FY2000 (total = $19 billion)

The numbers for FY00 contrast sharply with those shown in Figure VII–2 (data from Ref. 12), approximately 20 years ago. At that time, DoD received 11 percent of the total federally funded basic research.

2. Present and Past Defense Basic Research Funding Compared

The long-term funding trends for DoD basic research are shown in Figure VII–3. The lower curve shows funding in current (then-year) dollars. The upper curve is in constant dollars (corrected for inflation) and shows the funding in FY01 dollars. The long-term trend is one of declining funding for DoD basic research from the peak funding years of 1964–67. The funding levels decreased from 1967 to 1976 and then rose to a new peak in 1993 (which was lower than the 1967 peak). Since 1993, as shown in Figure VII–3, there was a decline in real terms of 27 percent in 5 years (FY93–FY98) in basic research funding. There has been some recovery over the past 2 years.

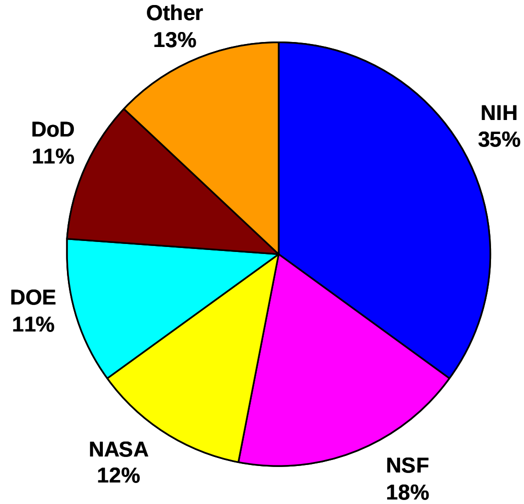


Figure VII–2. Basic Research Funding Distribution Among Federal Agencies, FY1979 (total = $4.7 billion)

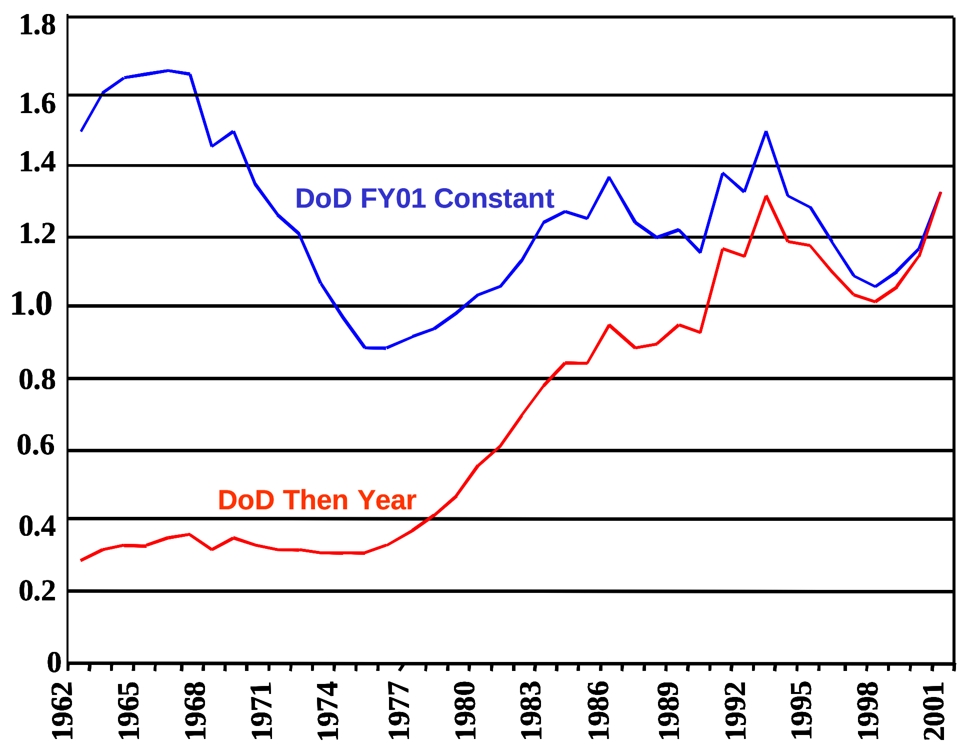


Figure VII–3. Long-Term Funding Trends for DoD Basic Research ($ millions)

3. FY01 and FY00 for Science and Technology Compared

The DoD Research, Development, Test and Evaluation (RDT&E) Budget Appropriation for FY01 is $41.36B. The amount budgeted for 6.1 Basic Research is $1.3B or 3.1 percent of the RDT&E total. Figure VII–4 shows the funding for Science and Technology (S&T) by funding category (Basic Research 6.1, Applied Research 6.2, and Advanced Technology Development 6.3) for each military department and for the defense agencies.

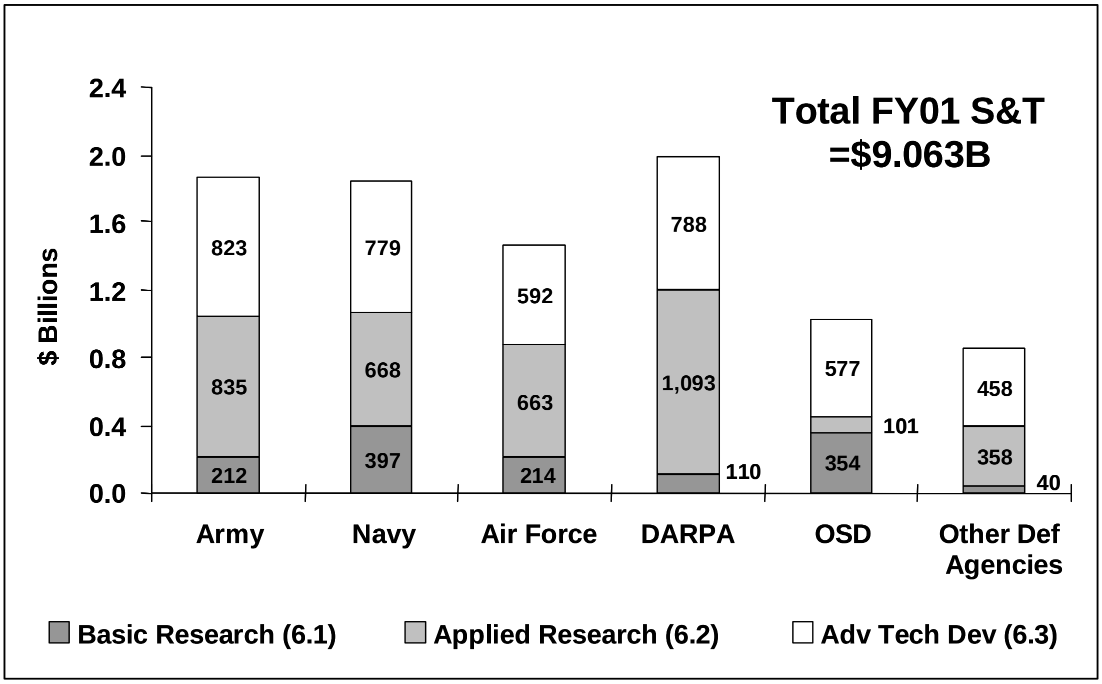


Figure VII–4. FY01 DoD S&T Appropriations Budget

The FY01 DoD science and technology appropriations budget is shown in Figure VII–4 in terms of the amounts appropriated to the Departments of the Army, Navy, and Air Force, and DARPA, the Office of the Secretary of Defense, and other defense agencies. Figure VII–5 shows the corresponding data for FY00.

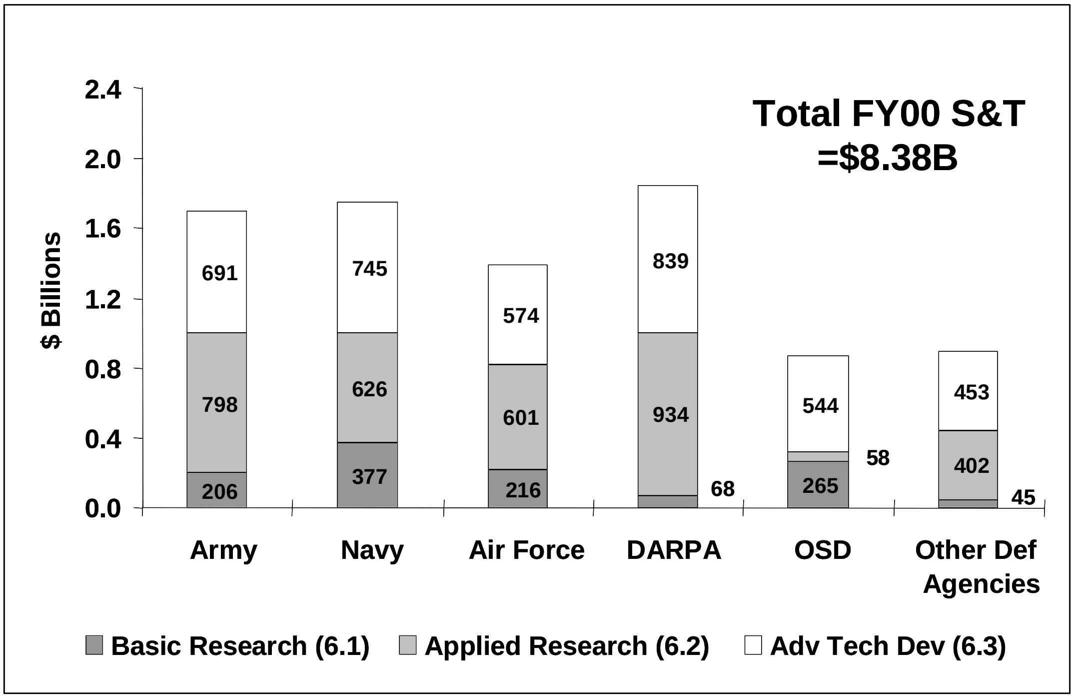


Figure VII–5. FY00 DoD S&T Appropriations Budget

4. Funding for Performers of Defense Basic Research

Figure VII–6 shows who performs S&T research for DoD. The principal performers of basic research are the universities (56 percent of 6.1 dollars), whereas applied research and advanced technology development is performed most often in industry.

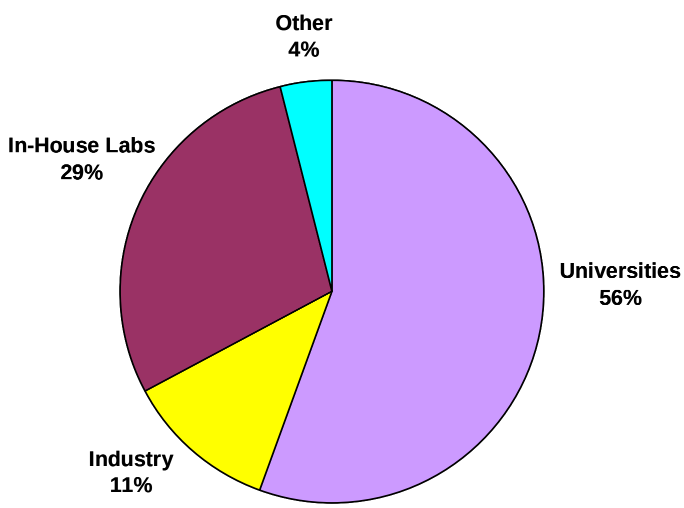


Figure VII–6. Performers of Defense Basic Research

5. Funding Comparisons by Disciplinary Areas

DoD is the principal supporter of basic research in some key technology areas, as shown in Table VII–1. An analysis of federal funding of basic research to universities indicates that DoD provides the majority of funds for academic research in electrical and mechanical engineering (data from Ref. 13). On an overall basis, DoD provides 38 percent of the research funding of the colleges of engineering, which are a major element of support for the nation's engineering programs.

Table VII–1. DoD Percentage of Federal Funding to Universities

Life Sciences			2%
Psychology			5%
Physical Sciences			9%
Environmental Sciences			13%
All Mathematical and Computer Science			39%
	Mathematics	22%	
	Computer Science	42%	
All Engineering			38%
	Aeronautical Engineering	42%	
	Astronautical Engineering	22%	
	Chemical Engineering	14%	
	Civil Engineering	11%	
	Electrical Engineering	71%	
	Mechanical Engineering	63%	
	Metallurgy and Metals	44%	
Source: National Science Foundation (NSF 99–333)			

B. TOTAL FUNDING FOR DEFENSE BASIC RESEARCH

Funding for all DoD activities is tracked in the DoD budget by program elements (PEs), which are numbered by five non-zero digits. All R&D PEs have for the first non-zero digit the number "6." Further, if the PE refers to an R&D activity that is basic research, then the second non-zero digit is a "1." The letter appended to the PE number denotes the service or agency responsible for its execution: "A" stands for Army, "N" for Navy, "F" for Air Force, "E" for DARPA, "D" for OSD, etc. Table VII–2 presents all PEs in basic research for the years FY1999, FY2000, and FY2001 (data from Ref. 13). **Funding values shown in this document are based on the tentative DoD budget completed on January 24, 2001, and may not reflect the actual President's Budget Request**.*

* Actual funding values supported by the Fiscal Year 2002 President's Budget Request may be viewed at *https://ca.dtic.mil/dstp.*

Table VII–2. DoD Basic Research Funding, by Program Element, Appropriated for Fiscal Years 1999, 2000, 2001, and President's Budget for 2002 ($ millions)

PE	Title	FY 1999	FY 2000	FY 2001	FY 2002
Services					
Army					
0601101A	In-House Laboratory Independent Research	12.1	13.9	14.3	14.8
0601102A	Defense Research Sciences	121.9	123.5	136.6	131.3
0601104A	University and Industry Research Centers	42.3	64.9	59.3	59.1
	Total Army	**176.3**	**202.2**	**210.2**	**205.2**
Navy					
0601152N	In-House Laboratory Independent Research	14.6	15.5	16.2	16.3
0601153N	Defense Research Sciences	339.4	351.4	377.6	382.8
	Total Navy	**354.0**	**366.9**	**393.8**	**399.1**
Air Force					
0601102F	Defense Research Sciences	197.2	208.2	212.7	210.8
Total Services		**727.5**	**777.3**	**816.7**	**815.1**
Defense Agencies					
Office of the Secretary of Defense					
0601101D	In-House Laboratory Independent Research	2.1	2.0	2.0	2.1
0601103D	University Research Initiatives	220.4	223.4	291.7	225.4
0601110D	Gulf War Illness	22.6	24.6	27.7	16.9
0601108D	High Energy Laser Initiative	0.0	0.0	0.0	6.9
0601111D	Government/Industry Cooperative Research	4.2	6.1	6.6	3.4
0601114D	Def Exper Prog to Stimulate Competitive Rsch	0.0	0.0	21.7	9.9
	Total OSD	**249.3**	**256.2**	**349.7**	**264.6**
0601101E	Defense Research Sciences	57.4	63.0	108.3	111.0
Chemical and Biological Defense Program					
0601384BP	Chemical and Biological Defense	28.8	42.7	39.5	39.1
Total Defense Agencies		**335.5**	**361.9**	**497.5**	**414.7**
Total DoD		**1,063.0**	**1,139.2**	**1,314.2**	**1,229.8**

Note: Some columns do not add exactly to the totals due to rounding.

C. CONCLUDING REMARKS

There can be no denying that the DoD Basic Research Program has provided many benefits to the nation. Even apart from its contribution to national defense—which is and always has been the primary goal—it has also paid off handsomely in other ways, such as training many of the country's most able scientists and engineers and guiding them toward the most productive technologies. These technologies have produced revolutionary changes in the way we live and work, and have contributed immeasurably to the national economy.

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*Suggested chairs, but should be elected by the group and rotated periodically.

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APPENDIX C: GLOSSARY

1D	one dimensional
3D	three dimensional
ABL	airborne laser
AFB	Air Force Base
AFOSR	Air Force Office of Scientific Research
AI	artificial intelligence
ARO	Army Research Office
ARPANet	Advanced Research Projects Agency Network (precursor to the World Wide Web)
AS&C	Advanced Systems and Concepts
ASBREM	Armed Services Biomedical Research Evaluation and Management Committee
ASW	antisubmarine warfare
ATR	automatic target recognition
BACIMO	Battlespace Atmospheric and Cloud Impacts on Military Operations
BMDO	Ballistic Missile Defense Organization
BRP	*Basic Research Plan*
C^3I	command, control, communications, and intelligence
C^4ISR	command, control, communications, computers, intelligence, surveillance, and reconnaissance
CBD	chemical/biological defense
CBW	chemical/biological warfare
COTS	commercial off-the-shelf
DARPA	Defense Advanced Research Projects Agency
DCoR	Defense Committee on Research
DoD	Department of Defense
DSTAG	Defense Science and Technology Advisory Group
DTAP	*Defense Technology Area Plan*
DURIP	Defense University Research Instrumentation Program
DUSD(AS&C)	Deputy Under Secretary of Defense for Advanced Systems and Concepts
DUSD(S&T)	Deputy Under Secretary of Defense for Science and Technology
EM	electromagnetic
EO	electro-optics
GaAs	gallium arsenide
GHz	gigahertz
GICUR	Government–Industry Cooperative University Research

GPS	Global Positioning System
IR	infrared
IT	information technology
JCS	Joints Chiefs of Staff
JLOTS	joint logistics-over-the-shore
JWCO	Joint Warfighting Capability Objective
JWSTP	*Joint Warfighting Science and Technology Plan*
LIDAR	light detection and ranging
LOTS	logistics over-the-shore
MCM	mine countermeasures
MEMS	microelectromechanical systems
MMW	millimeter wave
MOUT	Military Operations on Urbanized Terrain
MURI	Multidisciplinary University Research Initiative
NASA	National Aeronautics and Space Administration
Ni_2MnGa	nickel magnesium gallide
NIH	National Institutes of Health
NNI	National Nanotechnology Initiative
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
ODUSD(S&T)	Office of the Deputy Undersecretary of Defense for Science and Technology
ONR	Office of Naval Research
OSD	Office of the Secretary of Defense
OXR	Offices of Research (collectively the ARO, ONR, and OFOSR)
$PbMgNBO_3$	lead magnesium nitroboric oxide
PbTe	lead telluride
$PbTiO_3$	lead titanium oxide
PDE	partial differential equation
PE	program element
PEBB	power-electronic building block
POM	program objective memorandum
PRG	Program Review Group
QoS	quality of service
RDT&E	research, development, test, and evaluation
RF	radio frequency
S&T	science and technology

SBIRS	Space-Based Infrared System
SiO_2	silicon dioxide
SPG	Scientific Planning Group
SRA	Strategic Research Area
SRO	Strategic Research Objective
SWNT	single-walled nanotube
TARA	Technology Area Review and Assessment
T_c	critical temperature
URI	University Research Initiative
URISP	University Research Infrastructure Support Program
vdW	van der Waals
VLSI	very large scale integration
ZnS	zinc sulfide